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Paper No. 115

RECENT ADVANCES AND IMPROVEMENTS IN FOUNDING.

By

THOMAS D. WEST,* Mem. Am. Soc. Mech. Engrs.
Cleveland, Ohio, U. S. A.

Improvements in the construction of foundries and their appliances, to cheapen the production of castings made from ferrous and non-ferrous metals, since the introduction of electricity and compressed air as a motive power in foundries has been of a steady, persistent and increasing character. This advancement of founding has led to the creation of many new auxiliary industries that demand the employment of many persons possessing more or less of an engineer's education, combined with their having some fair, practical knowledge of the needs of founding.

Before these auxiliary industries commenced to supply foundries with their equipment, all such was made by the foundryman himself or was obtained from outside jobbing shops. The starting of industries to make a specialty of producing foundry appliances in their neatest and most practical form awakened many foundrymen to also devise improvements, resulting thereby in a rivalry that has been very stimulating and that has been chiefly responsible for the installation of the labor-saving appliances seen in modern foundries today.

In keeping with the improvements for handling raw materials for founding there are those for mixing, melting, molding, core making and cleaning of castings that have, in the past three decades, greatly revolutionized old methods for doing all this work.

The improvements in producing ferrous and non-ferrous metals have been greatly assisted by chemical studies, both by

* Deceased since the preparation of this paper.

makers and users, of the percentages of the elements contained in them, instead of producing metals by guesswork, and then being guided by the appearance of fractures to judge the grades desirable to make alloys or mixtures of metals from which to make castings.

The advancement in core making and molding has been due to a few gaining a fuller understanding of the principles involved in the art of founding, to the use of better equipment for handling molds and to the use of molding machines.

The cleaning of castings has progressed sufficiently to keep fully abreast of the other machine manipulations in founding, due mainly to improvements in tumbling barrels and to the invention of sand blasting, pneumatic and hydraulic tools and electrical appliances specially designed for founding.

In connection with the great improvements of appliances to produce better castings and cheapen their production, we have the almost universal adoption of specializing, wherever such can be done to any advantage, to still further reduce the cost of manufacture.

The improvements in all the varied machine operations of founding and the adoption of specializing have been so vast of late years that it is entirely out of the question to undertake considering their description in detail in a single, or even several large papers. However, as some one or two of these features may be considered fairly comprehensively in a single paper, I will confine this one principally to a treatment of constructing foundries and the use of molding machines and other labor-saving appliances in connection with means to improve the quality of castings.

The writer has endeavored to make the paper comprehensible and of interest to those not especially familiar with founding, as well as to those who may be experts therein.

Intricacies of Founding Demanding Special Consideration.

Any extended inspection of foundries of today will show that the most revolutionary factors which have brought about the improvements in the art of making castings have been in the radical departures in the designs of foundries and in the methods for handling molds and castings. While much has been published by trade papers and engineering journals to

set forth supposed improvements in this field of engineering, attention has not been called to mistakes, and often rather absurd features have been installed in the thought that they would prove economical in the production of castings.

Thousands of dollars have been spent in endeavors to utilize machinery, buggies and turntable systems, etc., to handle molds and to mix and convey sand to them, which would not only increase the cost of producing the casting over hand labor, but, in some cases, be so entirely impracticable as to be finally discarded. There has been failure on the part of many managers to recognize the difference which must exist in the design of a plant for handling molds and liquid metal as compared with one intended to make pins and needles, railroad rails or tin cans by machinery, wherein all the raw materials can come in at one end of the factory and have little or no interference to prevent their going out at the other end a finished product.

The sand and dust of a foundry, in connection with the frail character of sand molds and the demands for instant action when the liquid metal to pour them is at hand, are all factors which must have full consideration in the design of a plant. Any proposition for equipping a foundry with complicated or "must go" appliances, based upon experience in other industries, is apt to lead to trouble. It is always well for engineers or inexperienced founders to be guided partly, if not wholly, by those of intelligence who have been brought up in the actual work, instead of ignoring all such counsel and going ahead egotistically, as some have done to their sorrow and loss.

Installation, Advantages and Advancement of Molding Machines.

There are problems in the designing and use of molding machines, as in the construction of foundries, that should be considered from the viewpoint of the experienced foundryman, if optimistic opinions as to the general advantages of machinery over hand labor are not to be allowed to blind the designer as to practical operating conditions which must be met.

Not long ago the writer made a special inquiry of a number of foundries to learn the extent to which they had adopted

molding machines and the views they held as to their advantages. I can best impart information obtained from these sources by publishing extracts from a few of the letters received, which I will place here under numbers, as follows:

No. 1 states, "We have increased our melt from a maximum of about five tons per day to 17 tons per day and our entire increase has been due to our using molding machines. All of the men who run these machines were simply handy men that we broke in ourselves and we have never had these machines operated by a regular molder".

No. 2—"We have about 75 men which I consider molders, the balance, about 125 men, are men that we have broken in on special jobs such as molding machines, follow-board work, etc".

No. 3—"When our foundry is running to its full capacity, we produce about 25,000 tons per year and employ from 175 to 200 molders. It probably will interest you to know that we have not one molding machine in our plant, unless you would so classify a few of the original old-fashioned squeezers, and we know that we are producing as much per capita and doing the work at as low a cost as our competitors who are using machines on certain classes of work".

The following are what can, more strictly than the above, be termed jobbing foundries:

No. 4 employs 84 regular molders and ten molding-machine operators.

No. 5 engages 24 regular molders and ten machine operators.

No. 6 has 80 men making molds, 15 of whom are machine operators.

No. 7 has 78 skilled molders and 40 handy men working on machines.

No. 8 states they have 120 regular molders and 50 machine operators.

A study of the above diversity in the employment of regular molders and machine operators shows it to be greatly dependent upon the following seven features: First, the character of the work; second, the design of foundry; third, the scarcity of skilled molders, compelling proprietors to train handy men to make their molds; fourth, indifference of some

firms to encourage installation of improvements; fifth, differences in the ingenuity of the supervisory force to devise ways and means whereby certain castings can be made on machines; sixth, keen competition compelling founders to utilize molding machines; seventh, whether a shop is closed or open in regard to unionism.

In the third case we have a condition displaying the difference in the achievements of shops that may easily exist, due to one shop having a thoroughly broad, experienced and good executive production manager, while another concern may be lacking in this regard. However, it may often be a question whether, if such an able management should decide to utilize molding machines, the results obtained with the machines would not be ahead of those of the average foundry which has adopted machines.

In keeping with points raised in the above paragraph, it can be said that, as a rule, it is not the designers of molding machines who have been responsible for their success. This has been due more to brainy executives and broadly experienced molder foremen or managers. Some castings are being made today by molding machines, through ways and means devised by these able men, that, a few years back, would have been thought impossible.

The plan of constructing patterns, mold boards, flasks, core arbors, and methods for handling the molds have often more to do with making possible the production of intricate forms of castings by the use of molding machines, and at a greatly reduced cost over hand labor, than the actual machines themselves. Nevertheless, the great accomplishments in reducing costs of production could not be obtained without using molding machines, no matter how ingenious the able molder founder may be in devising ways and means to do so.

The question has been raised whether the gradually increasing use of molding machines would not in time do away entirely with the need for highly skilled or broadly experienced molders. While molding machines will continue to displace the "regular molder", there is nevertheless a very large and varied class of work for which molding machines cannot be utilized, especially in jobbing foundries. It is safe to affirm

that founding will ever demand the services of a large number of "regular molders", some of whom will need as high skill and ingenuity as are demanded in any line of mechanical industry.

The System Most Adaptable for the Use of Molding Machines.

There are two methods for making molds. One of these comprises what is called "bedding in". This demands that the pattern be placed in the position in which its mold will be cast, and sand is rammed in, under and around it. The second system, called "rolling over", or "turning over", required the pattern to be placed the reverse way, and the sand is rammed around and on top of it, after which the pattern, the sand and flask are "rolled over" to bring the mold into the position in which it will generally be cast. Molding machines are chiefly of practical use in "rolling over" work, which comprises, on an average, fully 80% of the combined production of all foundries.

There are four distinct steps in the use of molding machines for "roll over" work: First, the ramming of the sand; second, the "rolling over" of the nowel; third, the ramming of the cope; fourth, the drawing of the pattern. The "nowel" is the lower body of a mold, while the "cope" is the upper section, and between the two exists the joint, which, when the cope is rammed on and taken off from the nowel, permits the pattern to be withdrawn from its mold. The nowel and cope are generally rammed independently on the machine by methods to be noted later on. Again, the "rolling over" of nowels or copes, also drawing of the patterns, may be done, if desired, by following the practice which existed before the introduction of molding machines.

Four Different Methods Adaptable for Compressing Sand by Molding Machines.

The ramming of the sand to form a mold is now accomplished by one or more of the following methods: First, hand ramming; second, jar or jolt ramming; third, squeezer ramming; fourth, gravity ramming; fifth, roller ramming.

It is often necessary that the first method, or some hand tucking or ramming, accompany that of the machine, in order to have all parts of a mold properly rammed, or to obtain the

different degrees of density that may be desirable at joints, in pockets, cores, projections, etc.

The second to fifth methods comprise what is generally called ''machine ramming''. In this, as in all other lines of machine work, to produce accurate results as to specific densities, the molding machine requires skilled handling; while the hand, with the best skill, finds it difficult to produce or duplicate the uniform degrees of densities required in ramming molds. Because of the delicacy often desirable in obtaining specific densities of sand, it was thought by many that the molding machines would not be very successful. These anticipated difficulties have been overcome to such an extent, by combining hand ramming, when necessary, with that of the machine, that there now exists little, if any, of the old-time hesitancy to consider the adoption of molding machines.

Benefits of Strata Uniformity and Reversibility of Density in Face of Molds.

Aside from the question of the strata uniformity of density obtainable by ''machine ramming'', we have to deal with that of the reversibility of hardness, or whether it is better for the face of a mold to be of the greatest or the least density to be had by ramming. As this point should be considered in judging of the adaptability of the various machine ramming methods, to enable purchasers of molding machines to select them intelligently, I have taken space here to discuss the subject in its relation to the various types of machines.

Advancement in and Results of ''Jar'' or ''Jolt'' Ramming of Molds.

The so-called ''jar'' or ''jolt'' machine method of ramming molds was originally protected by a patent taken out by Hainsworth, in 1869, having the following broad claim: ''The packing of sand, for a mold, in a flask, by raising the same, together with the pattern and letting them all drop upon a hard bed, substantially as shown and described''.

There seems to have been very little realization of the merit involved in this jolt method of ramming sand until after the expiration of Hainsworth's patent. This was, no doubt, due to the lack of appliances necessary to make a practical use of the system. Such appliances were, in 1878, patented by

Jarvis Adams, but it was not until compressed air became a common medium for the transmission of power that we find jolt-ramming machines commanding the serious attention of founders.

Jolt ramming of molds causes the undermost part of the sand in a flask to be the most dense, and from this greatest density at the bottom, or from the face of the mold, there will be a uniform decrease in its compactness to its top surface. This is exactly the reverse of the condition as to bottom and top densities of sands found in roll over molds that are rammed wholly by hand labor. For this reason there was much skepticism by molder foundermen as to the utility of jolt ramming, it being held by many that the bottom face of a mold should always be softer than its underneath supporting body. Men

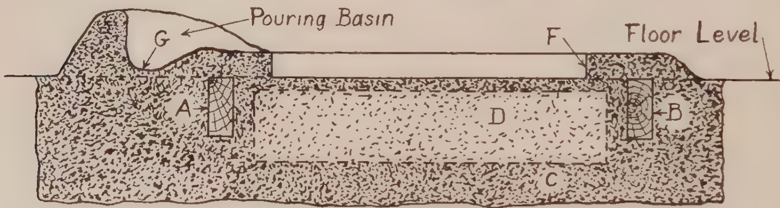


Fig. 1. Casting "Open Sand" Plates on a Soft Bed.

of broad experience in jobbing foundries were among the first to perceive the error of this. To show the practicability of having the face of certain molds the hardest, I illustrate, in Fig. 1, and describe below, the conditions involved in the making of "open sand" castings, a process requiring no top covering or cope.

Hard Face and Soft Under-Supporting Body for "Open Sand Molds".

Wherever castings can be used that are not required to be of an exact thickness and may permissibly be rough on one of their faces, such as castings for floor plates in rolling mills, they may often be made by "open sand" methods, after the plans seen in Fig. 1. In describing this sketch, we will presume the molder to be making some plain, plate casting requiring only one face to be smooth, and which may range in area from one foot up to twelve feet, or more, square or round.

In making such "open sand" molds, as Fig. 1, without venting, the foundry floor may be excavated to a depth of 6 to 24 inches; the larger the area of the plate casting to be made, the deeper, as a rule, the excavation. The digging having been completed, "straight edges" A and B are leveled and fastened in place. This done, loose or riddled sand, as at D, is shoveled in to fill the hole, and so as to protrude from a 1/4 in. to 3/4 in. above the top edge of the "straight edges" A and B. This protruding sand is now packed, by one or more of several methods, to depress it to but a little above the top of the "straight edges" A and B, after which another straight edge is used to "strike" the sand off level and smooth with the faces of A and B. This gives a comparatively hard face to the mold, while all the sand below it is of a less density, as left by the shovel in throwing it gently into the hole. The fact that the sand under the face of the mold is of a soft, porous character, as shown, generally permits the escape of all gases, when pouring the open mold, without the necessity of using vent wires, which are required when such under-bodies of sand are rammed as by hand methods in "roll-over molds". If the face of such an "open sand mold" as Fig. 1 is not made dense, as described, the metal, when running into the mold, would be more apt to form a salamander or bulky irregular mass of sand and iron, than to furnish a casting of the character desired.

Necessity of Having a Hard Rammed Under-Supporting Body of Sand for Molds.

To illustrate a very radical contrast in density of sand required in certain cases to that required for the making of "open sand castings", we turn to what is more in keeping with the hand ramming of "roll-over molds", as is to be seen in Fig. 2. Here we have a pipe casting nine feet in diameter by five feet high being made in green sand. All the sand below the dotted line H had to be rammed so hard that the vent holes, I, were made by using a hammer to help drive the 1/4 in. vent wire down into the cinder bed J.

In the making of the first one of these pipe castings, the mold was no sooner filled with metal than its static pressure forced crevices in the bottom of the mold, to such an extent that all the metal escaped to an under strata of quicksand

which was some three feet below the bottom flange of the casting, and only a few pounds of the several tons of metal were ever found. This fact is mentioned to impress the necessity of there often being radical differences in the densities of the sand forming the bottoms of such molds as those shown in Figs. 1 and 2, as well as in other cases that might be mentioned. It is to be understood that the body face K of the mold, forming the lower face of the bottom flange, was rammed but little harder than the face of the "open sand mold", or

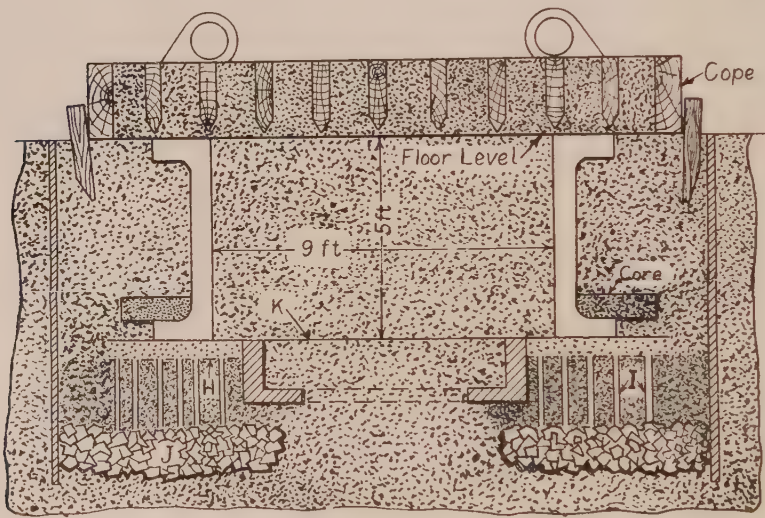


Fig. 2. Casting a 9-ft. Pipe in Green Sand with Lower Flange on a Hard Bed.

not nearly so hard as the underneath body below H. The body of sand between K and H being vented with a ⅛-in. wire down to the large ¼-in. vent holes seen at I, permitted the metal to lie quietly on the lower face of the mold, while the stonelike "under-hardness" of the sand below H prevented straining of the mold or casting, and avoided any further losses after the experience cited above.

Advantages of the Reversible Action of Squeezer's Methods in Compressing Sand.

In considering the "squeezer" method of compressing sand to make molds, whether by pneumatic, hydraulic, electric or

hand power, we find that it has an advantage over jolt ramming, in that it permits the face of a mold to be the hardest or the softest portion of the sand comprising it, as may best suit conditions. To illustrate these features, Fig. 3 is given. Here, by driving the wedges L and M, the sand is pressed downward upon the pattern N, causing the sand to have the least density at the face of the mold. However, we have a strata uniformity in the vertical degrees of density, ranging from one face of the mold's body to the other, similar to that obtainable by jolt ramming. Whether pressing the pattern N up into the sand, as by the wedges at O and P, would be pref-

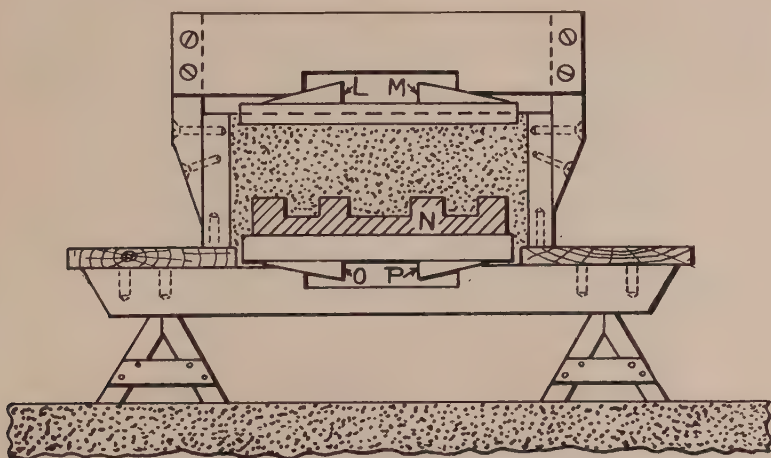


Fig. 3. Reversible Actions in Squeezing Molds.

erable, will naturally depend upon the character of the casting to be made. If neither pressing up or packing down the sand will give the best conditions for the casting to be made, then the vent wire, at some sacrifice of time and labor, may be used to largely, if not wholly, do away with danger of a mold "blowing" or "scabbing", which would result in a defective casting.

"Gravity" Ramming and Uniform Density Throughout the Sand.

The practicability and rapid adoption of jolt and squeezer ramming methods, caused inventors, including engineers and

founders, to seek for other systems that might be of service in mechanically compressing sand in molds. This resulted in the recent introduction of what are called "gravity" and "roller" methods for packing sand. These systems have been recently installed in a number of foundries and have advantages that commend them for making quite a large range of certain kinds of castings.

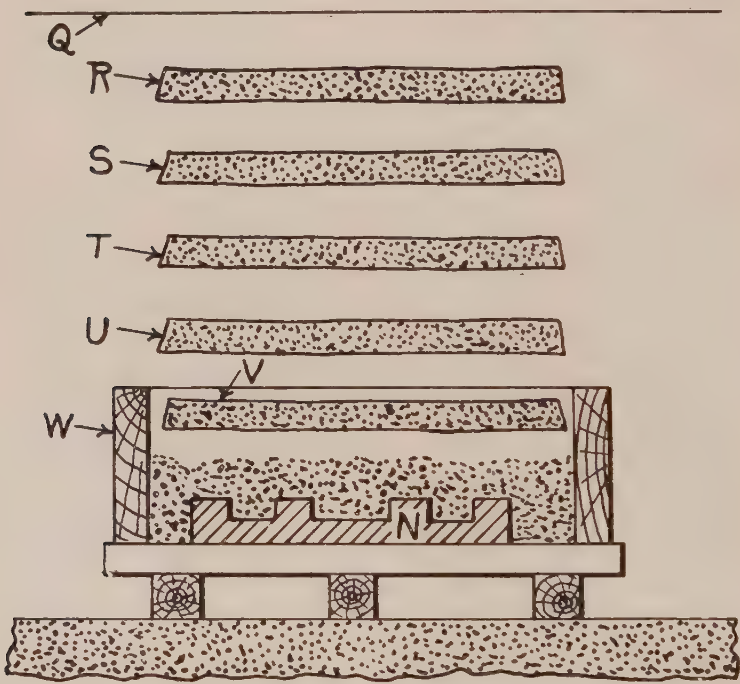


Fig. 4. Packing Molds with Falling Bodies of Sand.

The general principle involved in gravity ramming will be understood by reference to Fig. 4. Here, at R, S, T, U and V, are seen falling bodies of sand coming from a delivery height, as at Q, to fill the flask W. This method, like the jolt and squeezer methods, requires mechanism to control the operations necessary to attain the desired ends. Any person studying the illustrations, Figs. 3 and 4, should readily perceive that to make these principles possible of utilization in making vari-

ous kinds of castings, it was necessary to devise some special, ingenious appliances. As these cannot but be interesting and of value to all those seeking to understand the practicability of these systems, I will illustrate, later on, some of the latest devices being installed in foundries to make castings by machine operations.

The gravity-ramming system is one that gives results which differ greatly from the jolt or squeezer methods, in that the dropping of the sand from any chosen height gives a vertically uniform density from the lower face, or the first face to receive the sand, to the upper portion, which is the last to

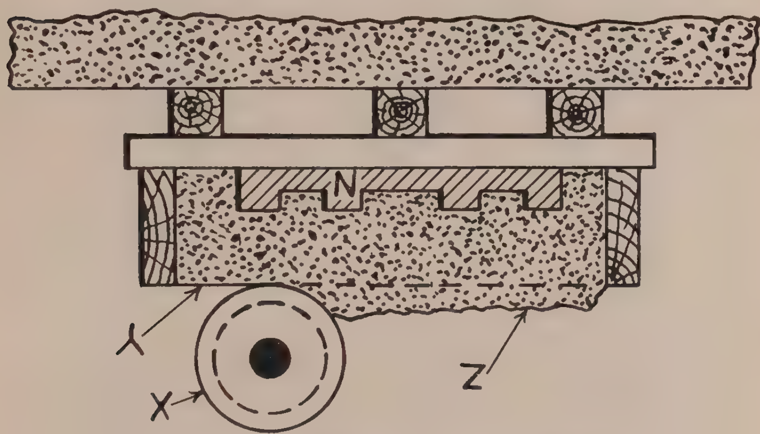


Fig. 5. Roller Compression of Sands to Ram Molds.

be filled. It can be readily seen that any desired degree of uniform, vertical density is obtainable by varying the height of the fall of the sand. I will, however, defer further discussion of these features until later, and will take them up in connection with the illustration of a machine used in the actual practice of making molds, which is seen in Fig. 17.

Roller Compression of Sand and Its Distinctive Features.

The most recent introduction of machine methods to pack sand in molds comprises the use of a roller, as illustrated by Fig. 5. Here, the roller X, having a solid bearing at each of its ends, as at Y, when moved forward and backward the nec-

essary number of times compresses the sand, seen at *Z*, to the desired density in the flask.

This roller method produces a result similar to that obtained by squeezers when pressing the sand downward onto a pattern, in that the face of the mold is the softest portion. If the cope face were desired to be the hardest, it is possible, in the case of strictly flat surfaces, to obtain such by the roller method, merely by having the sand compressed downward from the face of the mold and then ''struck off'' and trowel finished to give it a smooth face. It is only in the making of thick or massive castings, as a rule, that the cope face requires to be very hard.

For large surfaces, where the castings are under one inch in thickness, it is generally desirable to have the cope surfaces, as long as the sand can be held up rigidly, as soft as practicable. This permits the air in the mold and gases in the sand to find a ready release as the metal comes up suddenly to strike the cope's surface. This escape of gas is much freer than if the sand were as compact as it would be if jolt ramming were used, unless there was plenty of venting carried down close to the cope's surface. This roller method of compressing sand has features that commend it for various kinds of special castings.

Introduction and Utility of Power Hand-Ramming Appliances.

A very novel and useful appliance for ramming sand that is becoming very popular in modern foundries is seen being used by a molder in front of Fig. 6. These pneumatic hand rammers are used chiefly for what is called ''butt ramming'', as seen in the illustration. A man will not only do from 20 to 30 per cent more work with this tool than if ramming molds by hand, but will also save himself much hard toil. This latter factor has influenced founders to install and to have these tools used steadily in their plants. This tool is not only being used, as shown, for floor work, but for bench molding also. Air pressures of 30 to 100 lbs. per square inch can be used to operate them. The pneumatic rammer being attached to a rubber hose, as shown at the left side leading up to the top of the rammer, makes it convenient for use at any spot over large areas of ground.

Improvements in Perfecting Jolt Ramming of Molds.

The following description of designs found necessary in utilizing jolt ramming for founding should be of service to those who desire to intelligently purchase and use machines

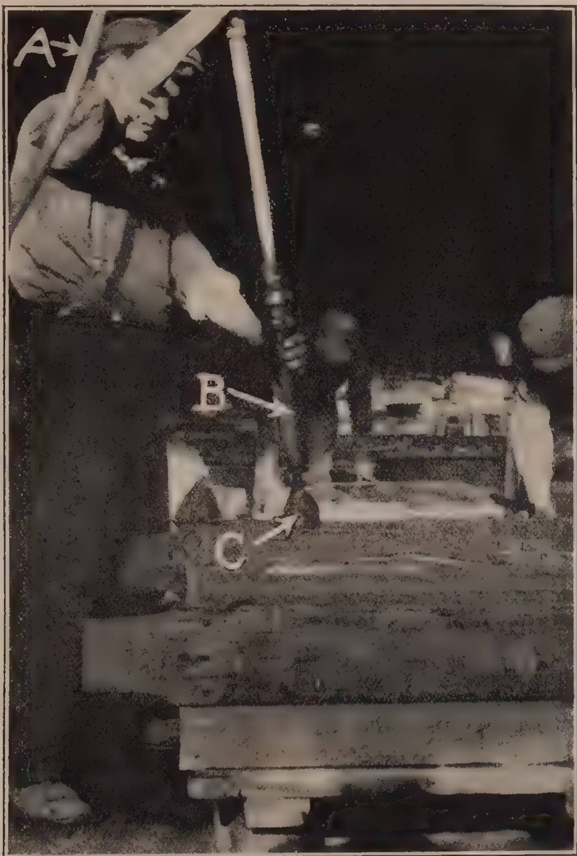


Fig. 6. Pneumatic Hand-Rammer.

of this type, and illustrates the reasons why the first introduction of jolt ramming by Hainsworth and others did not meet with much success.

Fig. 7 is a sectional view of what is considered an advanced type of a good, cushioned, plain, jolt ramming machine.

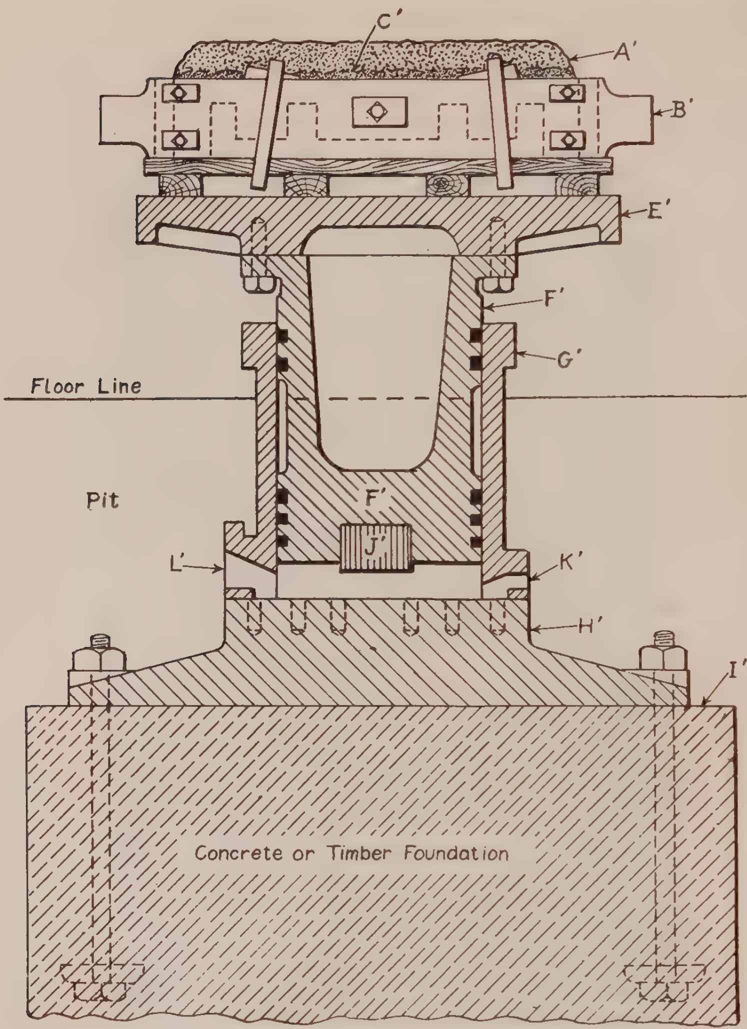


Fig. 7. An Air-Cushioned Center-Blow Jolt-Ramming Machine.

It shows the sand A′ in the flask B′ before it is jolted, and at C′ after the operation is completed.

The principal parts of these jolt machines generally consist of the table E″, piston F′, cylinder G′, base H′ and the foundation I′. The foundation is generally constructed either of all concrete or of heavy timber cribbing to cushion the ma-

chine's blows and to prevent jarring the ground. The jolt is obtained, in the machine shown, by means of the steel insert J′ striking the face of the base H′. Some machines make the "jolt" by the table striking the top of the cylinder, and again by the whole bottom surface of the piston, free of any steel insert, coming down, as a body, to strike the face of the base H′.

The distance the piston and table are raised in the jolting operations varies, in different machines, from ¾ in. to 2½ in. The best efficiency is generally obtained, in the character of machines shown in the illustration, by a lift of 1½ to 1¾ inches. These machines are found to be most efficient at a speed ranging from 100 to 160 jolts per minute. A "dead drop" of iron on iron with no rebound is not desirable. This, in its action, would be similar to a person taking two steps forward and one backward to make progress in walking. This feature was one which had to be developed by the test of actual use of the machines. The first machines were found to shatter the solid-rammed sand to such an extent as to make bad molds and produce defective castings, and also made it impossible to attain speed in jolting.

To overcome the above shattering evils, it was found necessary to retard the effects of a "dead drop" to a greater or less degree. This is now achieved by providing a controllable air cushion to partially check the blow of the piston and thereby decrease its deadening effect. Some have so perfected the manipulation of this air cushion as to cause an elastic rebound that carries the piston and table upward in such a way as to have the mold board, pattern and flask B′ respond to the same degree as the sand itself. It is claimed that the recent perfection of these features, in providing a proper cushion for the drop of a piston, has increased the efficiency of earlier jolt ramming fully 100%. In other words, the best type of existing jolting machines will ram about as many again molds in the same time as the uncushioned machines will.

The raising of the piston F′ and table E′ is achieved, today, either by compressed air, cams, or toggle-joint appliances. Air is used having a pressure of 60 to 100 lbs. per square inch, and is, at this time, the chief power used for operating jolting ma-

chines. Some machines have an inlet for the air, as at K′, to be exhausted through another opening, as at L′. Very recent machines have only one opening, which serves for both admission and exhaust. The valves of these late improved machines cut off the inlet air before the exhaust opens, thereby consuming less air in jolting the machine.

The past few years' rapid advance in the successful use of jolt ramming machines has created a demand for some very large ones. Mr. W. C. Norcross, Terre Haute, Ind., has patented appliances whereby tables as large as 7 x 14 ft. are operated, three cylinders being used instead of one. Almost all forms and sizes of large flasks may be rammed by these large machines.

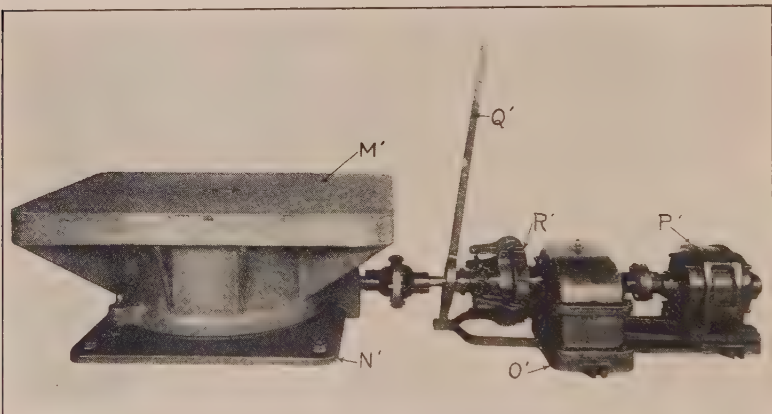


Fig. 8. Pridmore's Cam Jolting Electrically-Operated Machine.

chines. These large machines must be greatly reducing the cost of making large castings of various kinds, or else founders would not be encouraging their manufacture and installation.

Operation of Plain Jolt Machines by Means of Cams.

Fig. 8 shows a plain jolt machine, made by Henry E. Pridmore of Chicago, in which table M′ is operated by a cam, which works in contact with a roller follower forming one end of a bell crank. This whole machine is placed on a solid foundation so that the top face of the table M′ is about one inch above the level of the shop's floor. It is electrically driven, as can be be seen by the motor at P′, and is operated at will by the

handle Q′ opening and closing the clutches R′. These machines are made in standard sizes, with tables ranging from about two feet to six feet square; special sizes are built to order. Mr. Pridmore claims that it has been proven by actual tests that this electric jarring machine can be operated at one fifth the cost for power, as compared with the compressed-air machine; the cost of current being figured at 0.8 of a cent per kilowatt hour, and that of air being 1 cent for 215 cubic feet of free air compressed to 80 lb. pressure. This applies to machines of the same size.

Shockless Jarring Machines to Prevent Transmission of Ground Waves.

An objection that has been found by some to the use of plain jolt-ramming machines, such as have been described above, is the shock they transmit to the ground, and the damage it may cause to molds having any hanging bodies of sand in the copes, protruding green sand cores, etc., when the mold is in close proximity to the jolting machines. The shocks may also affect the foundations of buildings and machinery.

With a view of eliminating the shock or ground waves created by plain jolting machines, there is made what is termed the "Shockless Jarring Machine", shown in section in Fig. 9. This machine does not require any massive concrete or heavy wooden cribbing to support it. It can be placed on any plain foundation sufficiently solid to sustain its total static load.

The shock of this machine is deadened by a number of heavy springs, seen at its base, and by means of the compressed air used in operating the machine. The jolt action is obtained by the combined cylinder and table T′ working up and down on the piston U′. This table, in falling, strikes the plunger V′, which works in the cylinder S′, at its upper faced bearing, W′. When the compressed air is admitted to the jarring or jolting cylinder T′ to fill the space X′, the entire weight of everything, excepting the lower cylinder S′, is carried by the springs under the anvil, and they are, therefore, compressed and in readiness to expand when the air is exhausted and the table falls. At the beginning of this movement, the loaded table is impelled downward with a force equal to that which moves the anvil V′ and W′ upward, and it is

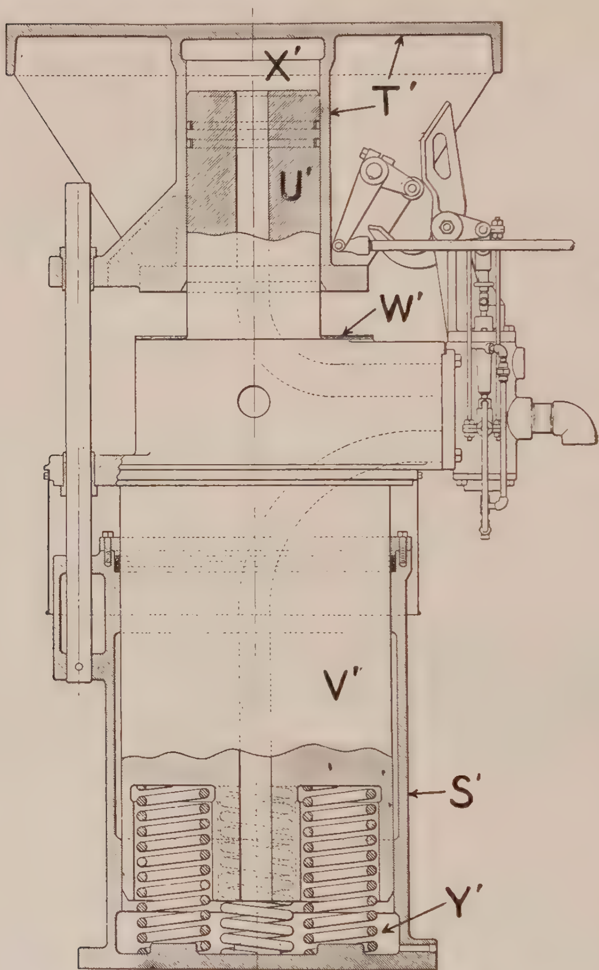


Fig. 9. Section of Tabor's Shockless Jar-Ramming Machine.

claimed that the loaded table and the anvil acquire substantially equal momenta, which neutralize each other when impact takes place. To compensate, in a measure, for the loss of spring pressure as the anvil rises, the exhaust from the jarring cylinder T′ may be carried into the anvil chamber Y′ before being discharged. This is accomplished by a combination valve, consisting of a large main valve of the steam-hammer type in

connection with a small pop valve such as is used on small power squeezers and split-pattern machines. These valves are attached to the anvil or plunger base V′, and the pop valve is opened and closed by tappets on the jarring table T′. When the table drops, the pop valve opens, admitting pressure beneath the main valve, which rises and puts the jarring cylinder in communication with the air supply, at the same time opening the anvil chamber Y′ to exhaust. When the limit of stroke is reached, the pilot valve opens to exhaust, and the main valve opens to drop the table. The air from the jarring cylinder T′ rushed into the anvil chamber Y′, expanding to much lower pressure, which is, nevertheless, very effective in the large anvil cylinder, and causes the loaded table T′ and anvil V′ and W′ to collide with greater force and effect upon the sand. The supply of air to these valves is controlled by an air cock at the operating stand, and the table runs automatically as long as the air is turned on. At the same time, the stroke of the table is controlled by another lever, adjustable, if desired, while the machine is running. The purpose of the pilot valve is to provide a controlling means that will give the delayed action required by the main valve. This always presents full openings during the table movement, up or down, and the ample lap on the ports gives time for expansion in the jarring cylinder, under light or medium loads, after the air supply has been cut off. Under full loads, or thereabout, there can be no appreciable expansion in the jarring cylinder.

These patent shockless jarring machines are made by The Tabor Mfg. Co., Philadelphia, Pa. They are constructed of various designs and for different conditions. The tables, for the different machines, range from about one foot up to six feet square.

Combination Jolt, Roll-Over and Draw-the-Pattern Machines.

In Figs. 7, 8 and 9, I have shown different types of machines having only the jolting action. In the following Figs., 10, 11 and 12, are illustrated features that are added to the mere jolt ramming of molds. The great advantages gained by machine packing of sand would naturally cause engineers and founders to seek for means whereby, after the ramming of a mold, it could be rolled over and the pattern be drawn by me-

chanical methods. This achievement has been accomplished in various ways, especially in the making of small or light-weight castings.

It is only within the past two or three years that attempts have been made to embody the three features, "ram", "roll-over" and "draw", making molds for medium and heavy castings. One defect in some of these recent machines is that

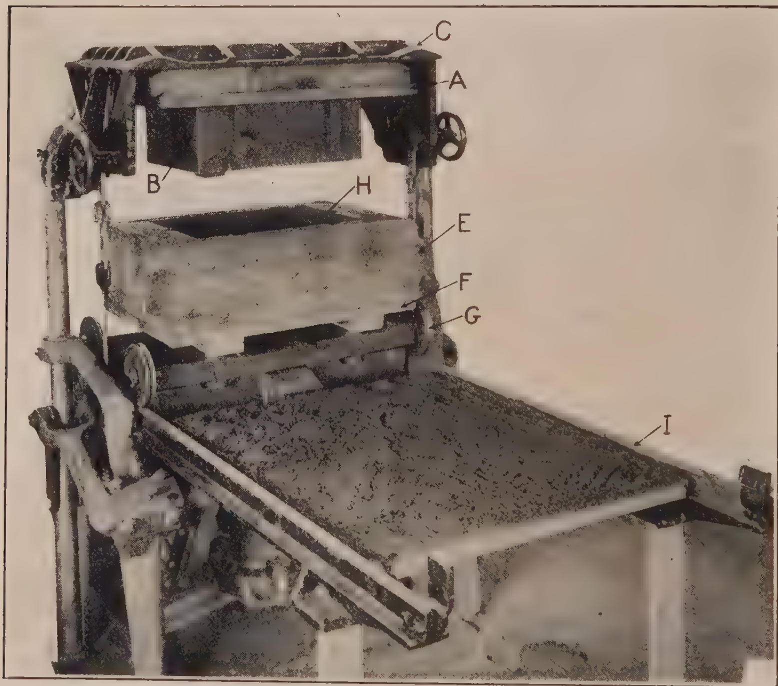


Fig. 10. Osborn's Electrically-Operated Jolt and Turn-Over, Drawing a Pattern.

the rolling-over and drawing of the pattern are rather too slow, so much so that little is gained over manual methods. However, much progress has very recently been made in increasing speed of operation. The machines shown in Figs. 10 to 12 are recent ones intended for medium-weight and heavy work.

The type of machine seen in Figs. 10 and 11 is operated by electricity. Its builders, The Osborn Mfg. Co., Cleveland, O., have simply applied electric motors to their air-operated

machine which is shown in Fig. 12. Both the air- and electrically-operated machines have the mold rolled over on its own center of gravity, the operation requiring very little power. In operating these machines, the mold board and pattern, A and B, Fig. 11, are secured to a holding or turn-over plate, C, which is turned by power to rest it on the jolting table D. The figure shows the mold board and pattern being

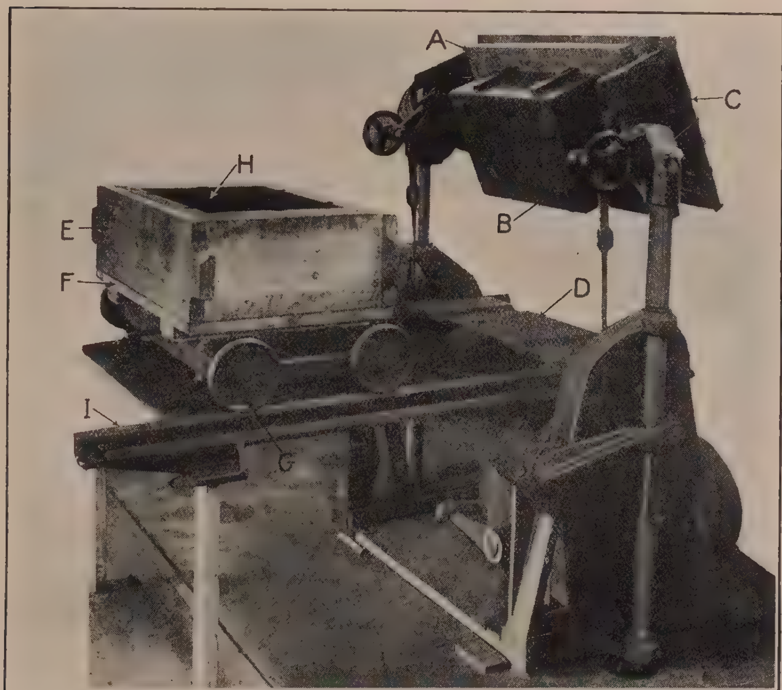


Fig. 11. Osborn's Electrically-Operated Jolt and Turn-Over, Replacing a Pattern.

turned over, after the latter has been withdrawn from the mold H, to again be seated on the jolting table D. After the plate C has come to rest on the Table D, the flask E, being turned upside down, is set on over the pattern B and is then filled with sand. This sand having been jolted and its excess "struck off", the bottom board F is bedded on in place. This work is followed by clamping the bottom board and flask to the turning plate C, and then turning them all over together, after which

the truck G is run under the flask to receive it, as seen in Fig. 10. The pattern B having been drawn from the mold H as shown, the truck G is then run out on the rails I, as in Fig. 11, to come under a crane, whereby the mold can then be conveyed to any part of the shop. In the making of small molds, this conveyance can, of course, be done by hand. as the floor line of these large machines is at a point P, Fig. 12, the lower part of the machine setting in an enclosed pit in the foundry floor.

Referring to Fig. 12, the turning-over or holding plate K is seen resting on the jolting table L, ready to have the mold

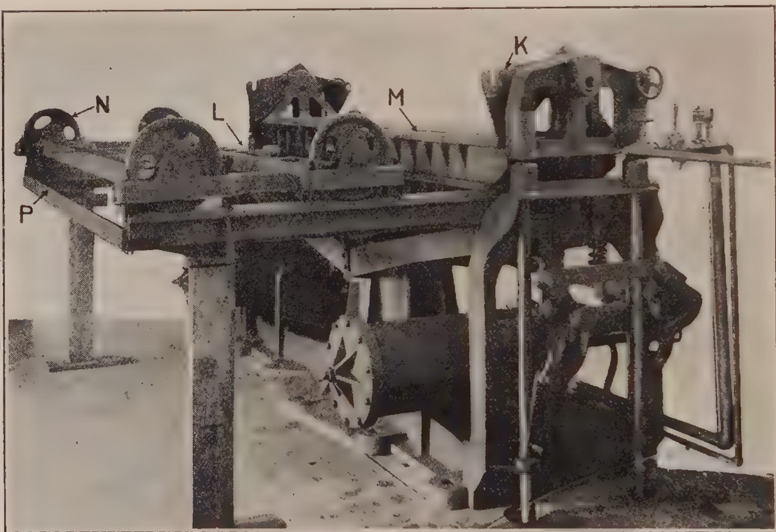


Fig. 12. Osborn's Air-Operated Jolt and Turn-Over with Draw-Plate Lowered.

board and pattern bolted to its face M, to thereby equip this machine for service, as is seen at A and B, Figs. 10 and 11. This air machine is constructed for heavier molds than the electrically driven one, and is capable of taking a flask 42 inches wide by 12 ft. 6 in. in length and having a pattern draw of 18″, which can be increased to 24″. This particular machine is made in eight different sizes, the smallest having a table 15½ x 20 inches. The lifting capacity, or the load that can be raised, by the large air machines, in jolting and rolling-over a mold, is 8500 lbs.

Swing-Arm, Jar-Ramming, Turn-Over, Pattern-Draw Molding Machine.

In the useful machine seen in Fig. 13 the pattern is secured to a swing arm at its face Q. This arm is turned over by the cylinder P, which brings the face side R down onto the jar rammer S. The flask is placed on over the pattern, and after

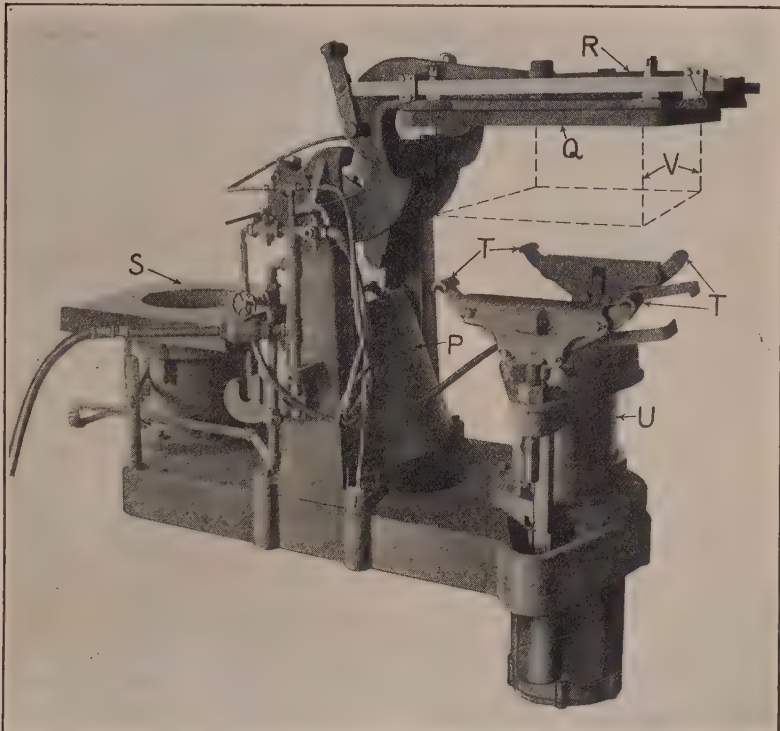


Fig. 13. International's Swing-Arm Jolt-Ramming Turn-Over Pattern-Draw Molding Machine.

the sand is jolted, to obtain the desired density, the bottom board is put on and all are clamped together, so that the swing arm may be brought back to the position shown in the cut. This done, the flask supports, TT, are raised by a piston at U to come up under the bottom board of the mold, represented by the dotted lines V, after which the turn-over frame, or swing arm Q, is released from the mold by freeing the clamps from the

flask, and then the whole mold is gradually lowered by a descent of the piston U. This action draws the flask and mold down from the pattern, since the latter is fastened to the swing arm at Q. Turning this arm up to a vertical position, or allowing the face R to rest again on the jar rammer, S, permits the removal of the rammed flask or mold, by hand or a crane, to any distant place on the floor of the shop. This is a pneumatic molding machine made by the International Molding Machine Co., Chicago, Ill., the ingenious arrangements of which have proved of much practical value in reducing the cost of making molds adaptable to its construction.

Hand-and Power-Squeezer Molding Machines.

The first machine to be used for compressing sand in flasks is conceded to be of the type known as a hand squeezer. It was applied solely to the making of small castings. A good illustration of one of the latest improved hand squeezers is seen in Fig. 14. The mold board, pattern and flask are placed with the battens of the first named resting on the table plate supports, A′. The sand having been filled into the flask, the machine operator pulls on the lever handle B′, which brings down the squeezer plate C′ onto the top of a battened board covering the sand in the flask. Further pulling down of the handle B′ squeezes the sand in the flask, from the top down, to the desired density or to the power capacity of the machine. The vertical distance between the points A′ and C′ can be changed to suit varying depths of flasks by raising or lowering of the cross bar D′, by adjusting the nuts E′ and F′.

This excellent type of improved hand squeezer has connected with it what is called a vibrator, seen at G′. This appliance vibrates the table A′, so that in drawing the pattern by hand it comes more freely from the mold, greatly decreasing any chance of its loosening or breaking any of its parts or joints. It also does away with the use of rapping bars, which often injure patterns and distort the size and form of the casting produced. The value of this device is especially evident in repetition work in making castings.

The principle involved in this vibrator is used in a variety of ways, on both hand and power molding machines of all classes, to aid the drawing of patterns. The recent introduc-

tion of the vibrator has made it possible to quickly draw many deep patterns, and also those having complex contours, without breaking or starting the sand of the mold. Prior to its

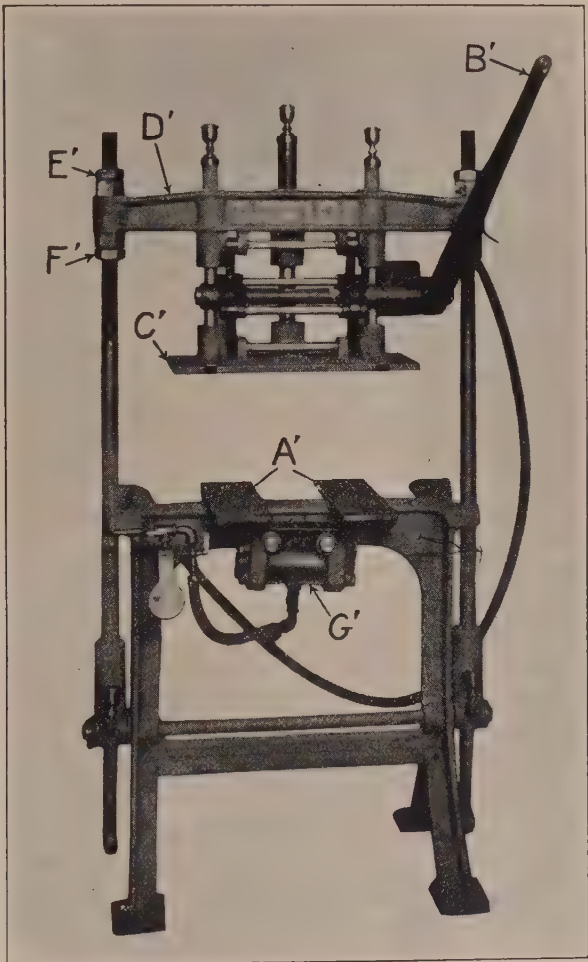


Fig. 14. Berkshire's Hand Squeezer and Vibrating Machine.

adoption, much trouble was often experienced in drawing such patterns without causing injury to the mold.

The great utility of hand squeezing machines soon led to

the adoption of power squeezers of various pneumatic and hydraulic types, Germany leading in the use of the latter. A very simple and effective power squeezer, designed by W. D. Fraser, is seen in Fig. 15. In operating this machine, the mold board, pattern and flask, represented by the dotted lines H′, are set on the table-plate I′. This table is cast solid with a cylinder K′. The piston, which is 12 in. in diameter, is bolted to the base N′. By turning the valve at J′, the cylinder rises from its faced joint at M′ to any required amount up to four inches. The average required of the cylinder and table is about 1½ inches. While the cylinder-head table-plate I′ is only 15 x 21 inches, the machine, it is claimed, can compress the sand in a flask as large as 24 x 30 inches. By turning the top plate P′, the distance between it and the table plate I′ is varied to take any height of flask within the machine's range. To admit of placing flasks and filling them with sand, the arm R′ is swung to one side, and on being returned to its working position, it is locked by means of the handle S′. This machine also has a vibrator, as seen at O′, which is controlled by the valve at L′. Both these hand and power squeezers are made by the Berkshire Mfg. Co., Cleveland, O.

Combination of Jolt and Squeezer Methods for Ramming Molds.

For castings of certain designs, and to suit certain shop and other conditions, it is sometimes very desirable to first jolt-ram the sand and then finish its compression by a squeezing operation. This has the effect of creating a uniform, vertical density of the sand, similar to that obtainable by gravity ramming, the chief difference being that any desired degree of variable hardness is better obtainable throughout the depth of a mold by this combination than by gravity ramming; and this also saves much jolting that might be detrimental to the life of a pattern or flask.

A combined jolt and squeezer machine is seen in Fig. 16. The cylinders T′ and U′ are pattern-draft cylinders used for lifting the table or flask frame V′, which carries the mold up and away from the pattern after it is rammed. The patterns are mounted on a pattern plate, resting on the jolt table, seen inside of the frame V′, and having a vibrator attached to it. The jolt mechanism is placed in the center of the squeezer

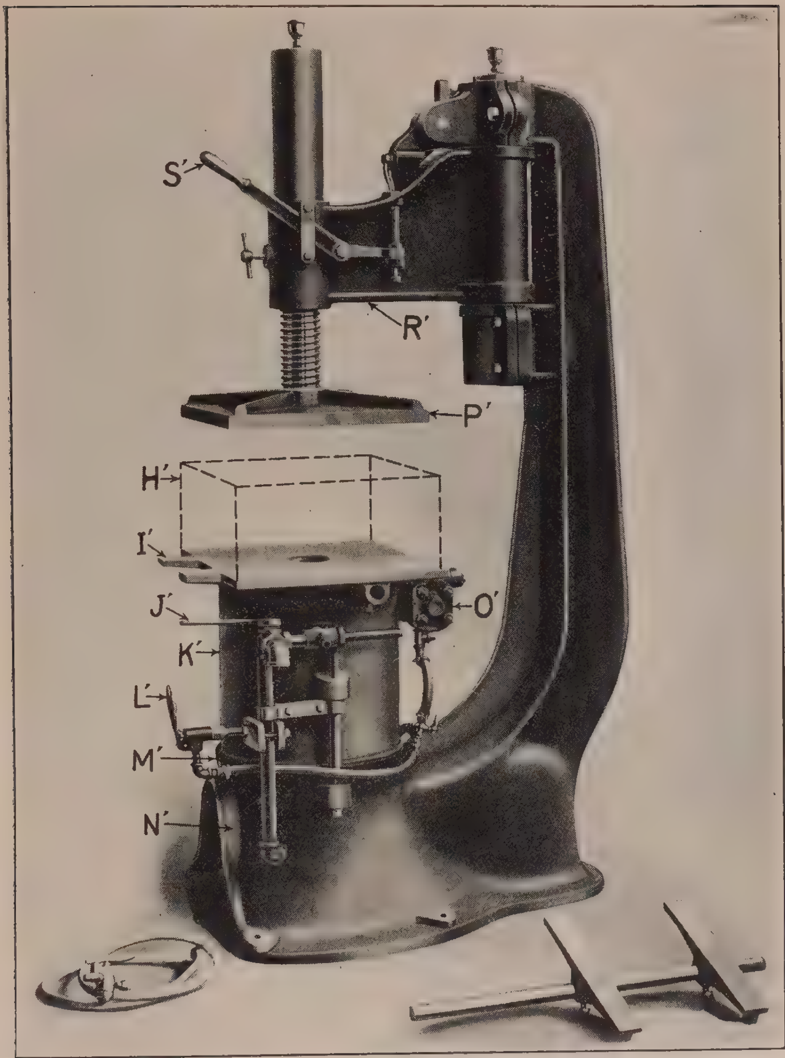


Fig. 15. Berkshire's Power Squeezer and Vibrating Machine.

cylinder W′. The squeezer beam Y′ drops back to permit placing and removal of flasks.

The machine seen in Fig. 16, which is manufactured by the Mumford Molding Machine Co., 2059 Elston Avenue, Chicago,

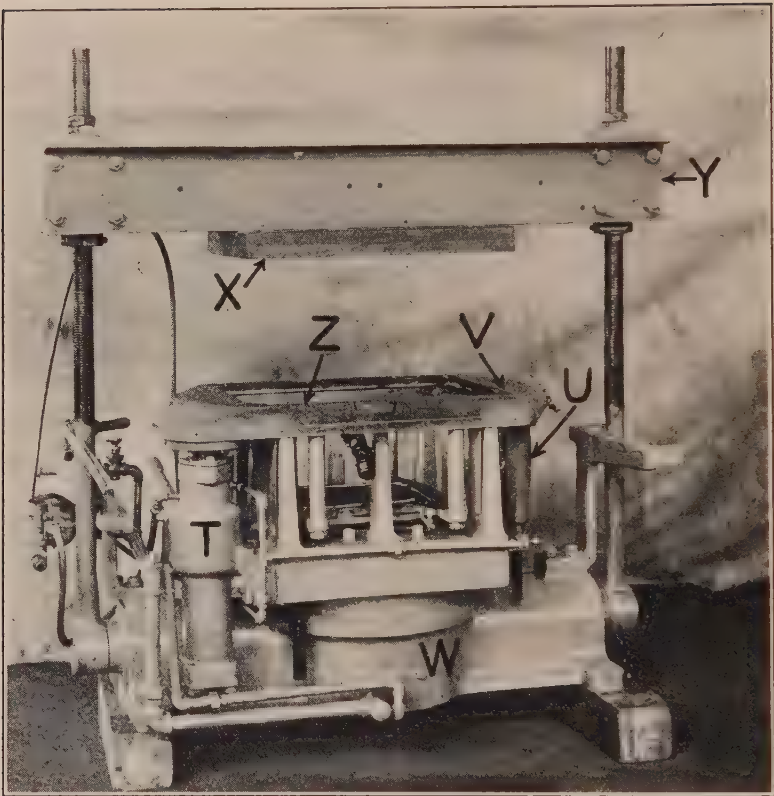


Fig. 16. Mumford's Combined Jolt and Squeezer Ramming Machine.

Ill., takes a flask 18 x 26 inches, and operates with air at 80 lbs. pressure. The principle involved in this combination machine can be utilized for varied forms of flasks or patterns.

Construction of and Methods for Operating Gravity Molding Machines.

While I have shown in Fig. 4 the principles involved in gravity ramming of molds, it is believed there are many who will be interested in appliances which make the principle applicable for use in founding. With this in view, attention is called to Fig. 17. In operating these machines, the sand is shoveled or dumped into a hopper bin from which a line of buckets, attached to sprocket chains, convey it up to a height,

from which it drops into the flask. This flask is suspended by hanger rods, which operate like a swing or cradle, permitting it to be moved in or out to catch the falling sand at any desired point in the flask, until it is filled with packed sand all over its area and to the desired height.

To swing the flask, or the cradle, in or out, as desired, in order to have the dropping sand land at the right spot, the swing of the cradle is controlled by hand for light work; and for heavy work, it is controlled by an extending arm operated by an electric motor in an ingenious manner.

The flask, cope or nowel, as the case may be, is, when rammed, turned over in the cradle, let down on rests, unclamped, and the cradle, with the pattern board attached, is then drawn from the sand or flask by the power of the machine. The flasks are carried away from the machine by a crane to the floors where they are cast. The manufacturers of this machine, Buch Foundry Equipment Co., Bridgeport, Montgomery Co., Pa., claim to have them in use making various different kinds of excellent castings at a greatly reduced cost, as compared with hand labor. The unique and ingenious construction of this machine cannot but command admiration from the thoughtful.

Construction and Operation of the Roller Ramming Machine.

In the description of Fig. 5, I have referred to recent achievements in utilizing a roller to pack sand in flasks. In this, as with gravity ramming, all should concede the desirability of machines embodying the roller principle. The working of the McDonald, patent, roller ramming machines, used for making a wide range of castings, is illustrated by Figs. 18, 19 and 20. In starting to make the mold, the flask H, Fig. 18, is placed on the mold board or match plate I, after which the roller guide and sand frame J is lowered to place, as seen at K, Fig. 19. After the flask has been filled with sand, the roller L is driven forward and backward by an air cylinder operated by a valve at M. The flask having been sufficiently rammed, the roller guide K is raised, as at P, Fig. 20, and the flask is now "struck off" and lifted off from the match plate or pattern, as shown at Q, thus completing the operation of ramming a nowel or a cope.

Fig. 18. McDonald's Roller Machine before Ramming a Mold.

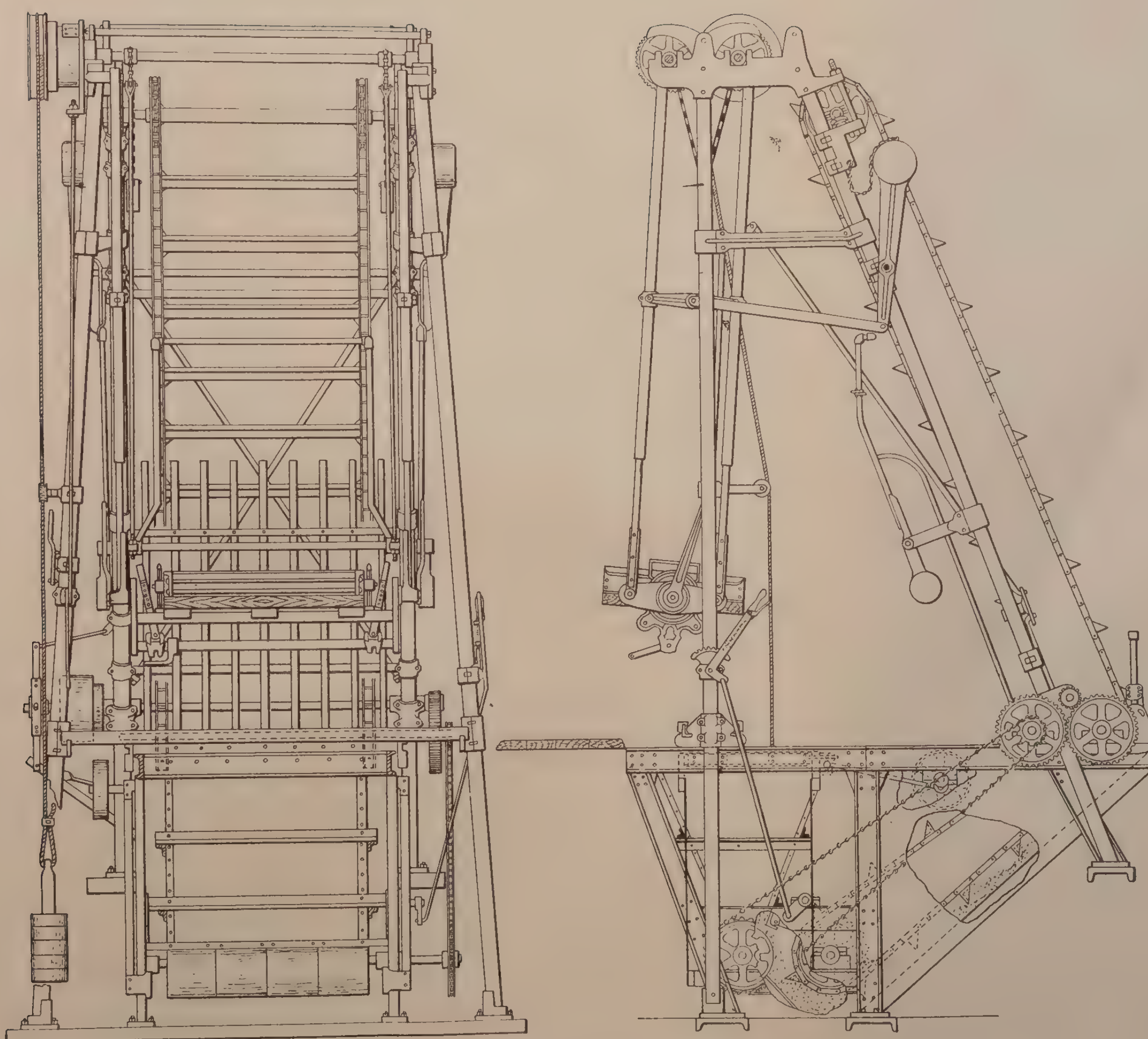


Fig. 17. Buch's Gravity Ramming Machine.

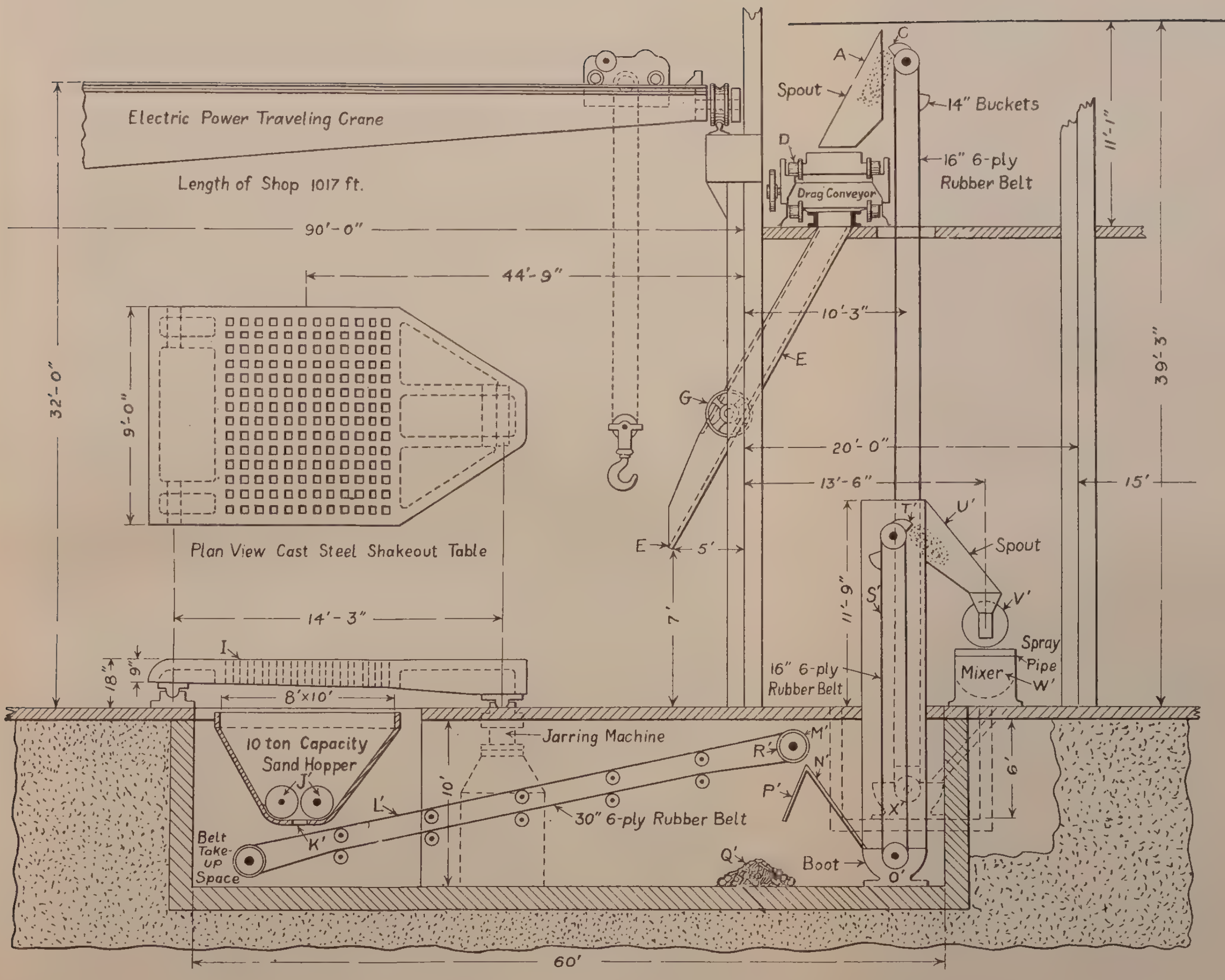


Fig. 23. Cross Section of Unit System and Plan of Shake-Out Table.

The track J not only serves as a guide for the roller L, but also as a means for retaining the sand on top of the flask while it is being rammed. If there were no means for holding the sand in sideways, the roller would push it off the sides of the flask as it travels along. It will be seen that the flange O of the roller L is somewhat less in diameter than the main cylindrical part of the roll. The difference in these diameters is double the thickness of the horizontal legs of the angle iron J, Fig. 18. The vertical legs of these angle irons, when in use, as in Fig. 19, project into the grooves between O and the main cylindrical part of the roll L. This guides the roll and allows it to ride freely upon the sand; but when the roll is off of the flask and going back to its initial position, its weight is carried on the parts O. These extensions, O, also serve to prevent the roll from dropping down into an empty flask and thereby breaking out the bars, in case the operator should run out the roll before the flask was properly filled with sand.

The sand-retaining feature of the angle J is a most important one, as it is this feature which enables the sand to be properly rammed at the edges of the flask, without hand tucking or hand ramming, preliminary to "rolling the mold". Another important feature is the "strike-off" S, Fig. 19, which travels in front of the roll and is supported by the small wheels N. This "strike-off" has a profile shape similar to the design of the pattern, and is so designed as to leave more sand over the longitudinal deep parts of the mold and less over the shallow parts, thereby giving a uniformity of ramming. This "strike-off" is so constructed that its position is independent of the vertical position of the roll itself, so that as the roll lifts up on the sand, while it is ramming the mold, the "strike-off" stays at a constant level.

Another ingenious arrangement, not shown, for ramming evenly where there are uneven contours to the face of a pattern, or where it has large projections which protrude above its general level, consists in using a flexible pad—composed of strips of oak, about two inches thick, bound together with steel cables running the entire length of the pad—which is placed on top of the sand that has been "struck-off" to a level surface. The underneath side of this pad is cut out to approximately

Fig. 19. McDonald's Roller Machine Ramming a Mold.

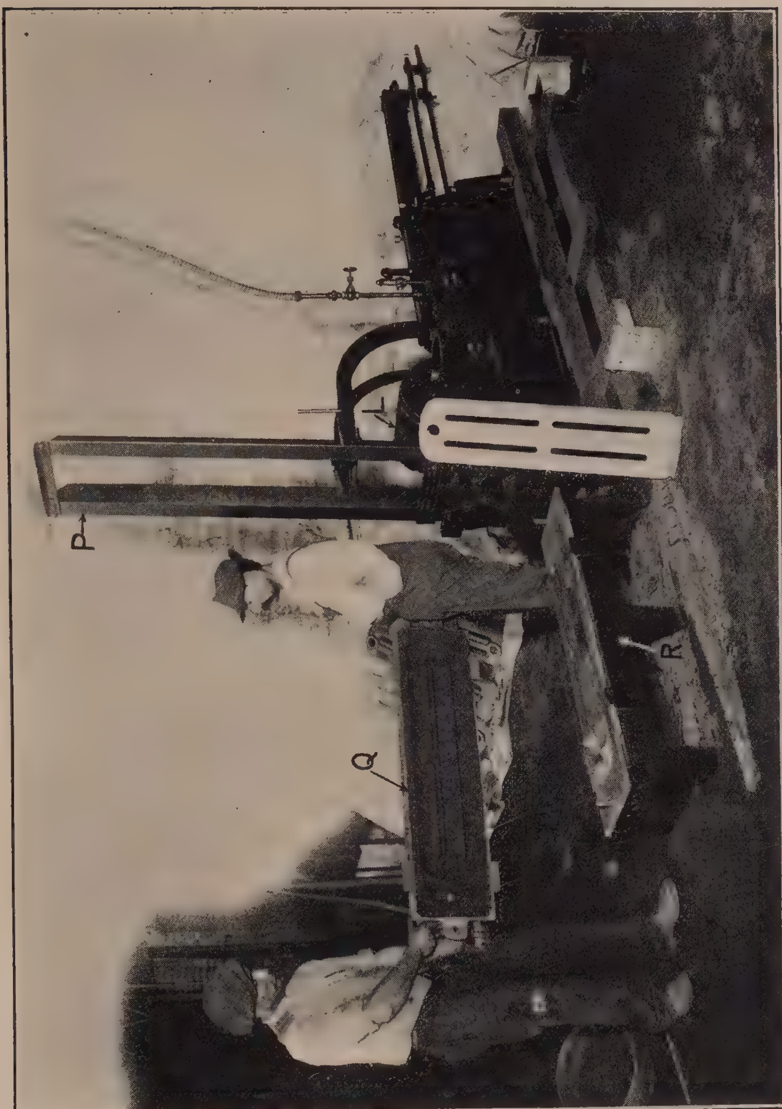


Fig. 20. McDonald's Roller Machine after Ramming is Completed.

conform to the contour of the pattern, so that when the roller is reciprocated to and fro over the pad, there is produced a more even density of the compressed sand than would be the case if a strictly level faced pad were used.

Tables, as at R, are constructed so that stripping plate patterns can be used when desirable, a method followed in many instances.

The larger-sized machines are electrically, and the smaller pneumatically, driven. The power, or rather the amount of air required for the pneumatic machine, is about three cubic feet, at 80 lbs. pressure, per half mold, 20 in. wide and 42 in. long. A three-horsepower motor is used on the electrically-driven machine, having rolls 30 in. wide, and such a machine is claimed to ram a flask 8 feet long in about 25 seconds. The power required for machines of other sizes is in proportion. These machines are built by The Snead & Co. Iron Works, Jersey City, N. J., to meet the demands for any practical size desired. Their smallest standard machine takes flasks 10 in. wide and 42 in. long, the largest a flask 30 in. wide and 15 feet long. They also build machines taking flasks approximately six feet square. The Snead Co. claims that they can build a McDonald roller ramming machine to take a flask six feet wide and 20 feet long.

Summary Comments on Molding Machines.

The foregoing has given a description of the four principal machine methods which are now being used to ram molds, in connection with rolling them over and drawing the pattern. The original manner in which these four methods, with the principles involved, are set forth, herein, should enable all interested in the production of castings to the more intelligently decide which is best adapted to meet the varying requirements, and also to stimulate further improvements, wherever such may be possible of attainment. It is to be understood that there are numerous modifications of the principles and machines shown herein, which have been designed and are in use, but is not possible to describe them all in the limits of space permitted.

Since engineers and founders have been awakened to the wide field which can be profitably covered by molding ma-

chines, much study and thought have been given to the subject, and the practical results achieved have far surpassed early expectations.

Improvements for Mixing, Screening and Conveying Sand.

In accepting the maxim that "one want begets another", we find that ability to quickly ram molds by machines demanded the creation of ways and means to mix and supply the sand quickly to them. "Necessity being the mother of invention", there has followed in the wake of molding machines the devising of various methods for mixing and conveying of sand to them, and also for general floor molding purposes, that should prove interesting and profitable to many engineers and founders. Any firm contemplating the use of molding machines will be going little more than half way if it does not investigate and consider installing some of the practical appliances for mixing, screening and conveying sand that are now obtainable.

One of the first steps toward the installation of auxiliaries, to cooperate with molding machines in reducing the cost of making castings, was the introduction of sand-screening and mixing appliances, of which there are numerous different designs in use at the present day. One of the most recent machines for this purpose is seen in Fig. 21. The sand is fed by a shovel, shute, or otherwise, into the open end, at A′, against a disc inside of the screen which breaks it up and scatters it around the screen's circumference as it revolves. Any refuse or pieces of iron, etc., that will not pass through the size of screen used, pass out onto a shute, or drop to the floor at the end D′, to be carried away by a wheelbarrow or other means The sand drops from the screen B′ into a mixing trough E′, in which there are a series of right- and left-hand paddles, which are revolved by the gearing F′. These paddles give the sand or sands a thorough mixing while it is being wet with water, oil or any liquid compound from the reservoir C′ through the pipes seen below it. After a batch of sand, whether for facing or cores, has been sufficiently mixed, it is discharged from the trough E′ by means of the lever G′, which opens an outlet at H′, and can be carried away from the machine by wheelbarrows or a shute.

There are five sizes of these machines now obtainable. Some dimensions of the smallest are marked on the illustration. This machine mixes four cubic feet, and the largest, 27 cubic feet, of sand per batch. The floor space required for the smallest is 2 ft. x 6 ft. 9 in., and for the largest, 4 ft. 9 in. x 11 ft. 10 in. The power required to operate the smallest is 3 hp., and for the largest, 25 hp.

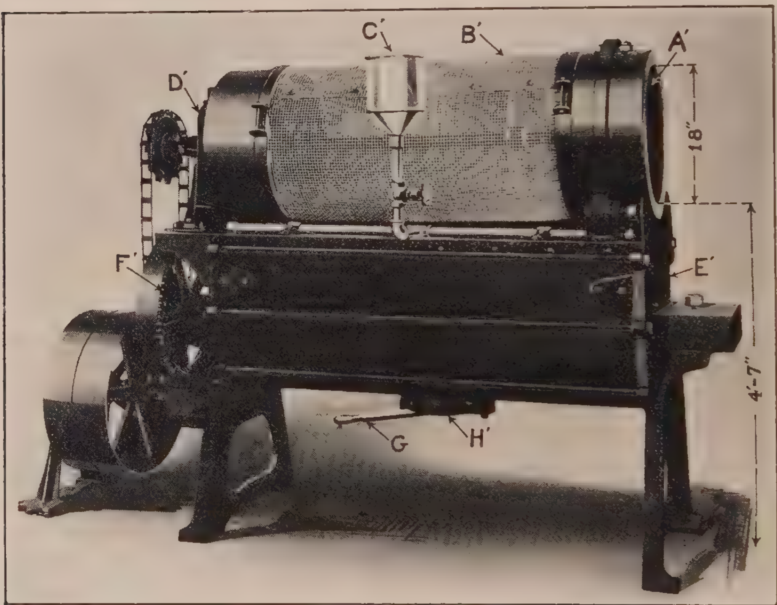


Fig. 21. Combined Sand Screener and Batch Mixer.

Value of Unit Systems for Shaking-Out Molds, Tempering and Conveying Sands.

Progressive founders were not long, after the introduction of such machines as seen in Fig. 21, in coming to believe that it was possible to have machinery to shake-out the castings and mix and convey the sand any distance, to an economical advantage. The past six years have witnessed many ventures to achieve these ends, some of which have proven costly failures. The results have been of great value, however, especially in the designing of elaborate sand-mixing and conveying plants in

specialty foundries. These past experiences have taught the great desirability of adopting what is now known as the unit system. This means making two or more divisions of a specialty shop and having an independent casting, shaking-out, sand-mixing and conveying plant for each section of the shop, so that if one unit or section breaks down, the whole foundry is not crippled. To illustrate this method we refer to Figs. 22 to 24, which exhibit a unit system that has been tried out

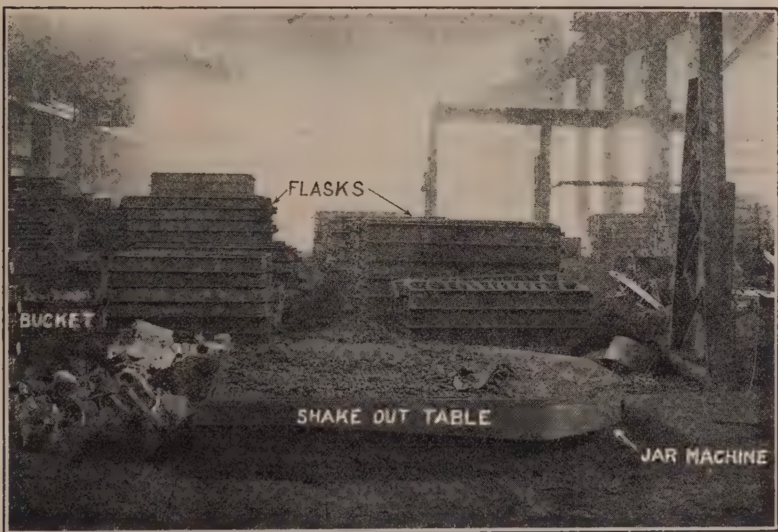


Fig. 22. Unit System. Grated Shake-Out Table in Foreground.

now for nearly one year by a large steel foundry, and which, it is claimed, has proven so successful that they will install two more such units, to be worked in connection with each other, as soon as business picks up to give work to employ them to an advantage. The main building of this foundry is 90 ft. wide by 1017 ft. long. The designers and constructors of this system, The Standard Sand & Machine Co., Cleveland, O., who are also makers of the appliance seen in Fig. 21, claim that this unit conveys and "tempers" 60 tons of sand per hour and that it has dispensed with the labor of 40 men.

Operation of a Unit Shake-Out, Sand-Mixing and Conveying Plant.

The product of the foundry, seen in Figs. 22 and 24, comprises, principally, one class of steel castings. The flasks used for making them are seen in Fig. 22. The molds are made in green sand. To shake the castings out of these flasks, they are brought, four at one time, by a specially arranged crane beam to the steel casting shake-out table, seen in the foreground of Fig. 22, which is a very practical and novel device. The castings are pulled from the table by hand and the sand is dropped through the grating I′, Fig. 23, into a hopper below it. This hopper holds ten or more tons of sand, which is fed out of it by means of two 16-in. heavy steel screw conveyors, J′, and falls through an opening K′, at the front end of the hopper, onto a 30-in. wide six-ply rubber-belt conveyor L′. A plan view of the shake-out table and belt conveyor would show the former situated in a side wing, permitting the jarring machine to have a foundation directly under one end of it and leading down to solid earth below the floor of the belt conveyor's tunnel, which is 60 ft. long.

The sand having been brought to the end of this belt, at M′, Fig. 23, drops onto a shute N′, which carries it down to and into the boot O′. The pulley R′ is magnetized and holds any iron that may be in the sand to the belt L until it falls to the shute P′, from which it passes to the floor at Q′. From the boot O′, the sand is carried up by means of a 16-in. six-ply rubber belt S′ having 14-in. sand buckets, T′, to the spout U′. From this, it passes to the revolving screen V′, which removes any wood chips or wedges that may be in it, besides screening it free from other refuse. This screen delivers the sand to a mixer W′, from which it travels along the shute Y′, to a boot X′. It is then conveyed to a spout A, by means of another 16-in. six-ply rubber belt B, having 14-in. sand-carrying buckets C. The sand falls from A into a drag conveyor D, and is then delivered to the spouts E, of which there are six in this unit system. A front view of the spouts is seen in Fig. 24. They are 6 ft. 5 in. apart, and hold about 2½ tons of sand each, which is delivered to dump buckets F by opening a gate controlled with a hand chain on the wheel G, seen in Figs. 23 and 24.

In the installation of the additional units referred to above, the firm intends to dispense with dump buckets and crane, and in their place use a conveyor, of a drag or belt form, to carry the sand from the spouts directly to where it may be needed for filling the flasks.

The unit system, Figs. 22 to 24, required one 5 hp. motor to drive the long upright belt B, and another of the same power to move the drag conveyor D. A 10-hp. motor is required to operate the screw conveyors J′, and one 25-hp. motor

Fig. 24. Unit System. Spouts for Delivering Sand.

is required for the remainder of the equipment. The appliances and all construction work of this unit system cost about $10,000. It has required much study and originality to devise this ingenious shake-out, sand-mixing and conveying apparatus, which should be very instrumental in suggesting ideas to further the reduction of costs of making castings for other specialties of ferrous, as well as of non-ferrous, metals.

Any one interested in this unit system, or in general plans for the construction of pouring, shake-out and sand-mixing and conveying appliances, can find a good article on the same, illus-

trating the Ford foundries, in The Engineering Magazine, January, 1915.

Mixing Sand Heaps on the Floor by Machines.

The past few years' endeavor to invent appliances for mixing sand ready to be rammed into molds has resulted in the development of power machines which dispense with the use of the hand shovel to a surprising extent. It would seem that we now have machines for mixing sand that are suitable for almost any conditions. Men looked askance at the first sand-mixing

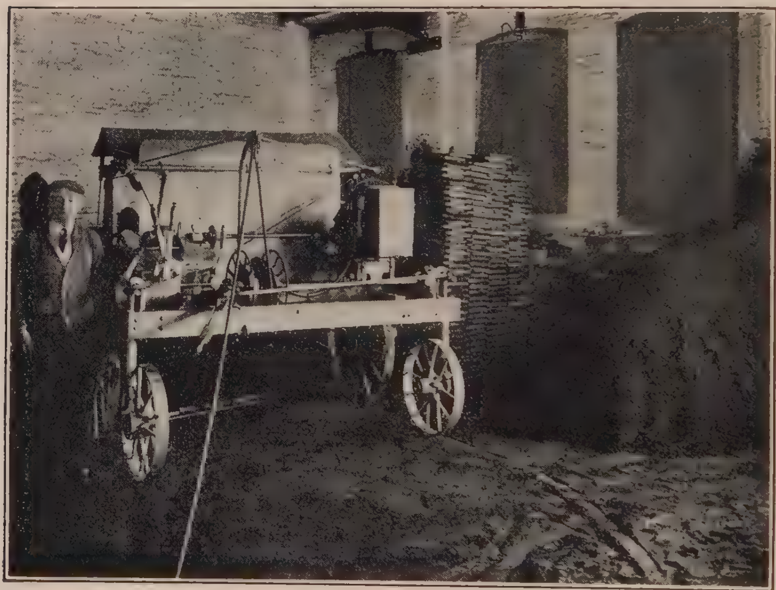


Fig. 25. Rear View of Auto Sand-Heap Cutting Machine.

and conveying systems, thinking that the utility of such apparatus was limited, since some of it did not work out to the advantage expected or had been an utter failure. However, we now find that, together with successful drag- and belt-conveying apparatus, there are auxiliaries, in the form of independent machines, which will mix or "temper" sand without removing it from the floor where it has formed molds.

A fair illustration of this innovation is exhibited by what are called "auto sand cutters", constructed by The Sand Mix-

ing Machine Co., 220 Broadway, New York, shown in Figs. 25 and 26. These machines best serve their purpose where there are regular, uniform sand heaps (free of scrap that might injure the blades) with few, if any, obstacles in the form of columns, flasks, shop appliances or uneven floors to prevent the machine being readily taken from one sand heap to another, or where conditions exist similar to those usually found in light-work and stoveplate shops.

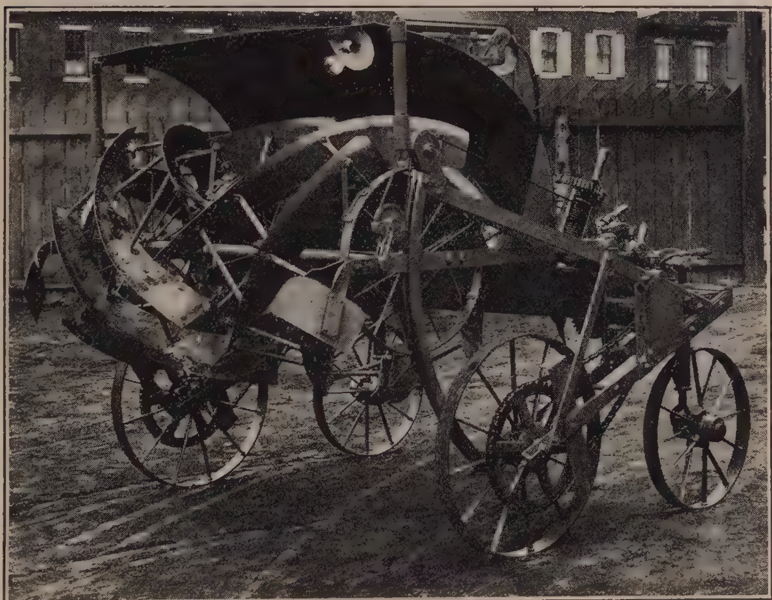


Fig. 26. Front View of Machine Shown in Fig. 25.

To meet the objection that obstacles prevent moving these "auto sand cutters" around conveniently, a machine has been constructed (Fig. 27) which can be operated advantageously when suspended from a crane.

In using the floor or the crane machines, water is thrown on the sand in the old-fashioned manner, after which the edges are shoveled in by hand, to roughly gather all the sand of a floor or heap in one windrow or long, raised pile. This done, the machine is brought over one end of the pile and its

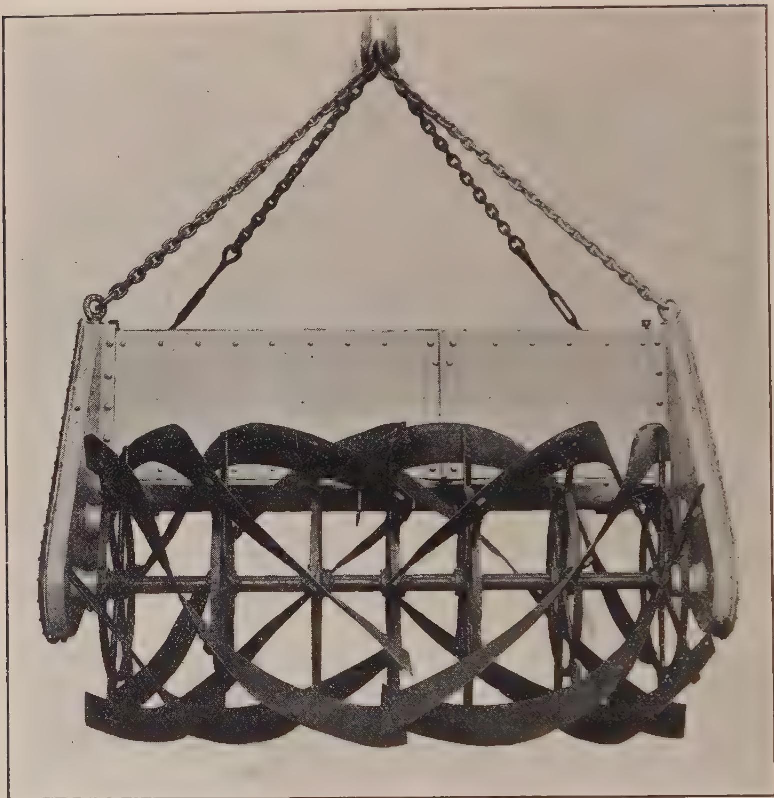


Fig. 27. Front View of Crane Sand-Heap Cutting Machine.

cutting operations started. If it is an ordinary molding floor, such as used for general light work or stoveplate, and the sand is properly wet down in the beginning, only one cutting over by the machine is generally necessary. In the case of bench molding, the sand is (after being wet down) shoveled up in a rough windrow and the machine started at the end nearest the bench. In this instance, it being required to leave the sand in one pile against the wall at the bench, it may take three or four cuttings by the machine to place it there. The machine moves a sand heap ahead about four feet at each cutting. A good illustration of a sand heap that has been cut and conveyed back to a wall at a bench is shown in Fig. 25.

Both the auto and crane sand-cutting machines have been found to produce a more uniform "tempering" of sand piles than is usually secured by hand shoveling and to generally greatly reduce the cost of such work. Especially is this true since it has come to be that not much more than 50% of those working at hand and machine moulding can handle a shovel skillfully, and that we are now being so cultured to death that few are to be found willing to work at common labor or to do the hard work of hand shoveling.

The motive power of the floor auto and crane sand-cutting machine is electricity. The requirements are for from five to ten horsepower, according as sand heaps are small or large.

Grab Buckets, Mixing, Conveying and Packing Sand.

I believe that few would now claim that progressive founders are not as wide-awake and ready to take every advantage of machinery as are the best leaders in other vocations. The very recent, popular adoption of grab buckets, by founders, to mix sands, etc., further displays their readiness to take the greatest feasible advantage of ways and means to reduce labor costs and hard work by the use of machinery, consistent with the production of good castings.

By means of a grab bucket, designed and built by Pawling & Harnischfeger Co., Milwaukee, Wis., a sand heap, as one example, 80 ft. long, 4 ft. high and 5 ft. wide, has, after being wet down, been thoroughly cut, or mixed, ready for the molder in 35 minutes, utilizing only the labor of one crane operator and one man who handled the rope that opens the buckets. After the sand has been wet, the mixing is done by raising it and letting it drop from a height. In wetting, prior to starting the operation of the grab buckets, sufficient water may not have been thrown on it to bring it to the desired "temper". In this case, more water can be sprinkled on, as needed, between the successive two or more hoistings required to give it a thorough mixing. The number of necessary lifts and droppings will depend greatly on the skill in applying the water and upon the character of the sand, as some grades are always harder to mix than others, whether the mixing be done by hand or power.

These buckets are also employed for conveying the sand any distance and for filling large flasks. Their value in the

latter use is increased by the fact that sand will pack itself to a greater or less degree, according to the height from which it is dropped. Large flasks may be partially rammed most economically in this way. Again, these buckets are found to be of value in excavating and filling holes in floors of shops that do much "bedding in" work, as it is here that falling sand, packing itself, required little other manipulation.

The grab bucket cooperates with the magnet in unloading cars, thereby assisting reduction of cost in handling raw materials; and both are appliances which may well be classed with the greatest production improvements that have forwarded the art of founding.

Increase in Quantity Is Not Sacrificing Quality.

Founders of all the various branches and specialties of iron, steel, malleable brass, aluminum, white metal and other alloy castings, while they have utilized the molding machine and sand mixing appliances in many ways, are to be commended for not having sacrificed quality to quantity. Quality has kept pace with quantity, so that, today, castings of all classes have an exterior appearance and internal solidity greatly superior to that obtained ten to twenty years ago.

The improvement in quality has been largely brought about by the following five factors:

(1) By a better understanding of the technical features of founding, largely secured through the liberality of experienced men and close students who have disseminated their knowledge and advanced ideas on the art by means of association papers and original, practical writings published in books and by the technical press.

(2) By the employment of brainy supervisors who are ever seeking improvement and who possess the executive ability required to achieve desired ends, combined with broad experience as foundrymen.

(3) By specializing and using the grades of sand and facings most suitable to the particular line of castings produced, by employing scientific methods in mixing and fusing of metals, and by using the best modern appliances to clean the castings.

(4) By the use of molding machines, which permit many

thousand tons of perfect castings to be made daily by machine operators of "handy men"; castings that otherwise could not be obtained readily, if at all, because of the great scarcity of good, skilled workmen and necessary executive molder foundrymen to supervise their labor.

(5) "Last, but not least", by the installation of sand-mixing, screening and conveying systems and sand-heap cutters that insure a better "tempering" than is generally obtainable by hand labor.

Influences Endangering the Success of Future Founding, and Needed Remedies.

The number of skilled molders is not increasing as rapidly as the demand of the trade. This is so true that were there not machines and "handy men" to help make the many thousand tons of castings that are being turned out this day (1915), founding would be in a sorry plight and unable to supply the demand there would be for skilled molders required to produce them.

The growing great scarcity of skilled molders and efficient molder-founder executives is partly, if not largely, responsible for the development and introduction of the molding machine and auxiliaries as found in many foundries today. Nevertheless, as there is a limit to the provision of substitutes and makeshifts for skilled artisans and broadly experienced supervisors in founding, I wish it known that many danger signals are out showing that there should be a change toward some radical measure that will insure the production of expert workmen and molder-founder executives. In this connection, it may be said, where there is a will, there is generally a way. If this way is not opened, the art of founding must soon further pass away. It will then be still more difficult to obtain the skilled workmen that are necessary to produce certain lines of castings. It will be a much harder task to find efficient, shop-trained production managers. Such a condition is bound to have a most detrimental effect upon the whole casting industry, upon general engineering, and upon the prosperity of the masses; an effect that the employment of the best unskilled labor, of "handy men", and of machinery cannot annul.

DISCUSSION

Mr. Dickie. **The Chairman, Mr. Geo. W. Dickie,**‡ Mem. Am. Soc. M. E., in opening the discussion referred to the unfortunate death of Mr. West since the preparation of this paper, to his marked ability in this field of work and to the great loss thus sustained by the profession.

Referring to the statement of Mr. West's, regarding the difficulty of getting molders, he said that machine molding had been forced upon the manufacturers, that handy men might be used to meet the great demand for castings.

Calling attention to the deep mold in process of construction, it took him back some forty-two years when the establishment for which he was engineer at the time took an order for 24 bone-black filters for the Spreckels' Sugar Co. The sections were 10 feet inside diameter and 3 ft. 8 in. in height. The foreman molder obstinately refused to use any but a loam mold. It took six days to get out the first casting and he estimated five days for each of the others. As they had to be in place within six months, it was evidently necessary to adopt a different method. He (Mr. Dickie) determined to try a dry-sand mold and had a new pattern made, taking some three weeks' time and developing much adverse criticism. Upon the completion of the pattern the flange and top were first taken off and then the body of the mold, and after skin drying the top and bottom of the molds, they were replaced.

The first casting was out in four days and the remainder at the rate of four per day, thus making a profit in place of a material loss. In his opinion molders have a strong feeling against apprentices, so that it is difficult to keep up the needed number of molders. There is a great hesitancy for men to go into the molding trade. He considered molding one of the fine arts, but that molding machines eliminate the necessity of skilled men and not many learn the trade.

Mr. Burlingame. **Mr. Luther D. Burlingame,*** Mem. Am. Soc. M. E., said that in the East they had found trouble in keeping up the number of skilled molders. They have school work for the boys in the foundry, dividing the work into classes, so as to give the men a chance at different lines of work. The molder's apprentice is made to feel that the trade is worth while and that there is a chance for advancement.

Inducements are offered to men from the technical schools to come into the foundries. It is one of the best paid trades in the mechanical line.

Mr. Fuller. **Mr. Benj. D. Fuller,**† Mem. Am. Soc. M. E. (by letter). Referring to the statement of Mr. West, concerning the factors involved in the advancement in core making and molding, he believed that a better knowledge of the proper material for a given class of castings has been of

‡ Cons. Engr., San Francisco, Calif.

* Industrial Supt., Brown & Sharpe Mfg. Co., Providence, R. I.

† Supt. of Foundries, Westinghouse Elec. & Mfg. Co., Cleveland, Ohio.

equal importance. In cores the use of the proper sand, the suitable core binder and the introduction of mixing machines to properly mix sand and binder, added to the use of better ovens to properly dry the cores, have resulted in marked advancement. Such economies as the saving of 50% of binder are made by using mechanical mixers over hand mixing. Better cores result from the use of the evenly mixed and tempered sand. Mr. Fuller.

A comparatively recent and valuable addition to the core room, and one not mentioned by Mr. West, is the machine whereby the sand is injected into the core box by a blast of compressed air. Fine results are being obtained from the use of this machine and its possibilities are great. The principle is also being applied to a machine for the making of molds, but has not, as yet, met with the same degree of success as the core-making machine, although promising much.

In the cleaning room, in addition to introducing proper tools and equipment, much is to be gained by a study of the proper lay-out, in order that castings from the time of leaving the molding floor may always advance to the shipper, not accumulate and "back track", causing congestion, delay, etc.

As Mr. West says, "Thousands of dollars have been misspent in the endeavor to use machinery equipment, etc". This is true and marks a step in the advancement of the founding business. The molding machine, invaluable when properly applied and used, is often applied when a proper study of pattern construction and the use of match boards with flasks to suit, will produce better results with a much less outlay of money and time. This applies chiefly to patterns from which castings are ordered in limited amounts. When molding machines were first introduced it was generally thought that their use applied to the simpler form of pattern only; this has been disproved. The proper pattern construction, in connection with the machine, has resulted in astonishing improvement in quantity and quality of production.

Mr. West might well have mentioned the fact, that in the pattern shop lies a great factor for the success or failure of the foundry. Where the foundry manager is capable, he should be consulted as to the pattern construction; he should in fact dictate the form and style of construction.

In molding a barrel-shaped casting, if the outer circumference of the pattern were separate staves attached to a center core or to heads similar to barrel heads, the casting could be made in the drag, a simple form of mold. But, naturally, most pattern makers would separate the pattern in the center, forcing the construction of a much more complicated mold and resulting in an inferior casting due to parting line, shifts and fins.

Foundries generally do not attach sufficient importance to the tempering of sand. It will be found a paying proposition in the majority of plants to employ sufficient help to work as a night force, removing castings from molding floors to cleaning room, wetting down and tempering sand, passing same through a mechanical riddling machine or through an inclined screen such as is used in street work or building operations to

Mr. Fuller. screen out gravel. Sand on the molder's floor after the casting is shaken out, wet down, cut over once and passed through a screen, will be found in the morning, when the molder arrives, to be in fine condition, permitting of his starting to mold at once and resulting in an improved product and the saving of many a bad casting, there being no greater source of poor product than improperly tempered sand.

The gases formed when a mold is poured must have full vent or passage of escape. A mechanically rammed mold being of even density offers less resistance to the escape of gases than a mold rammed by hand, as each stroke of the rammer leaves a dense spot at the rammer's point. These dense spots offer an obstruction to the escaping gases, causing the flow to zig zag about in a manner not met with in an evenly rammed mold such as results from mechanical ramming by the jarring or squeezing method. This explains the reason for the free use of the vent wire in hand work, not found necessary in machine molding.

The proper handling of the cupola has come in for more attention than in the past and is such an important factor as to call for careful study. Good coke, proper tuyeres, proper blast pressure, fluxes, etc., mean much. Our most successful founders today fully recognize this and their product speaks for itself.

Paper No. 116

RECENT PROGRESS AND PRESENT STATUS OF THE ART OF FORGING WITH SPECIAL REFERENCE TO THE USE OF QUICK-ACTING FORGING PRESSES.

By

A. J. CAPRON, Mem. Inst. C. E.
Sheffield, England

During the past 10 years, great developments have taken place in the art of forging, and over the widening field of industries, requirements in forgings have increased rapidly.

In the first place, larger forgings are required, particularly for the increased calibre of guns that have been coming into use, and for turbine drums, wheels and spindles; in many cases requiring an ingot of as much as 100 tons weight.

In the second place, forgings are being much more extensively used in preference to steel castings. This applies particularly to marine work where reliability is the first consideration, and some saving in weight is of more consequence than economy in production. It also applies largely to forgings of all kinds for general engineering work. When steel castings were introduced they were used in many cases to replace forgings, at first often made in iron and subsequently in steel, the steel castings effecting a great saving in the cost of machining, particularly in the case of articles of intricate form. But the introduction of high speed steel during the last 15 years has so reduced the cost of machining that forgings have been replacing castings, in many cases advantageously as regards the cost of production, and their use in this direction is continually extending. This development is greatly assisted by the improvements that have been made in the art of forging.

For the production of the heavier forgings, presses have been used in preference to hammers for as much as 30 years in

many of the large steel works, but such presses are comparatively slow in their action and it is only within the last 10 years that great improvements have been made in their design and construction, and more particularly in their speed of working, which have rendered presses suitable for almost all classes of work, except the lightest forgings, which come within the range of small steam hammers or drop stamps.

COMPARISON OF FORGING PRESS AND STEAM HAMMER.

The press possesses many advantages over the hammer in its effect on the material, in the manipulation of the forging, in output and economy in working, and in absence of noise and vibration, which, in the case of heavy hammers, is always objectionable and often detrimental to adjacent buildings and machinery.

Effect on the Material.

Dealing first with the effect on the material, the squeeze of the press penetrates to the centre of the forging, as is evidenced by the bulging of the sides of the forging at each stroke; whereas, the blow of the hammer has much more of a surface effect, often leaving the sides of the forging quite concave unless the power of the hammer is very ample. As a result of this difference of action, the hammered forging shows a slightly finer texture on the surface but a distinctly more open grain of metal towards the centre of the forging; whereas, the pressed forging shows a fairly fine and practically uniform texture throughout the entire section. Individual tests may not always show a very marked difference between pressed and hammered forgings because a good deal depends on the relative powers of press and hammer to the size of the forging, the temperature at which the work is done, and the subsequent annealing or heat treatment, but in the course of the regular manufacture of tyres, for example, it has been found that much better and more reliable tests have been obtained from the press than from the hammer. This advantage of the press is recognized by Government requirements for forgings which stipulate that for rolled or hammered steel the ingot must have an initial section 8 times the finished section, whereas those pressed need have only 4 times the initial section.

Manipulation of the Forging.

For the expeditious and accurate manufacture of forgings, a great deal depends on the ease and convenience with which the forging itself and the tools required for its production can be handled, and comparing the action of a press with the blow of a hammer, it will be readily understood that the advantage in these respects is entirely on the side of the press. In the first place, it is much more essential in working under a hammer that the forging should lie true on the anvil, otherwise a fair blow cannot be struck and an objectionable shock may be caused to the crane carrying the forging and, perhaps, also to the men who are manipulating it; whereas a press will bring the forging to its correct position on the anvil without causing any jar and without interfering with the effect of the forging stroke.

When using tools under a hammer, much greater care must be used to place them correctly and to hold them in position because the repeated blows of the hammer tend to displace them. A press, on the other hand, once the tool is correctly placed, holds it in position until the cutting or forging stroke is completed. This enables such work as cutting or necking to be done much more easily and accurately under a press than under a hammer. For making a tapered forging with a press, a wedge shaped block to give the correct taper can be laid on the anvil without any fixing. With a hammer, such an arrangement would require fixing to prevent its being displaced. To forge accurately to size with large presses, a scale or indicator dial can be used, worked from the crosshead, which enables the operator to read the reduction made at each stroke and to work the forging down to the finished size without any measuring. With small presses, a gauge piece is often used between the tool faces which enables the forging to be made exact to size. With a hammer neither of these methods can be used conveniently.

Output.

In almost all classes of work, the press has a great advantage over the hammer in the matter of output. The blow of the hammer produces a very limited effect, generally reducing the forging by only the fraction of an inch, whereas the press will make a reduction of several inches per stroke which, in

straightforward cogging or rough forging work, naturally increases the output enormously. A good modern forging press of 2000 tons will make as much as twenty 3″ (75 mm) strokes, or a total penetration or reduction of the forging of 60 inches (1500 mm) per minute. In rounding up or finishing a forging, such a press will work up to 60 strokes a minute so that it is as fast as a hammer in finishing and much superior to a hammer in cogging and rough forging. As an instance of the output obtainable with a modern quick acting press, a 2000-ton press of the steam intensifier type starting with a 45-inch (1.143 m) ingot has cogged down and finished a 30-ft. (9 metres) length of well-finished, 15-inch (381 mm) shaft in one heat, using only flat tools. With a hammer of equivalent power, this work would have required not less than 3 heats. As another instance, a 1000-ton press, working on 24-inch (600 mm) ingots, has forged 31 tons of 15-inch (375 mm) round shafts in 8 hours, and as much as 34 tons of miscellaneous forgings have been produced in 8 hours by the same press. These are undoubtedly performances which could not be approached by any hammer.

With forgings of a more intricate shape, the advantages of a quick acting press over a hammer are even more marked, because the same advantage in speed of penetration is obtained combined with much greater facility in handling the forging and, at the same time, the production of a forging more accurate to shape and size. As an instance, an 800-ton press, which is nominally equivalent to a 7-ton hammer, has produced the forgings for an anchor weighing 11 tons in 3 days. Properly, this size of work should have been done under a press of 1200 tons which could have cut the time occupied to about one half. In comparison, Mr. Chester L. Lucas (in Machinery, New York, Feb., 1910), mentions an 8-ton anchor as being forged under a 20-ton hammer, which is equivalent to a 1500-ton press, the time occupied being 27 days. This anchor was no doubt of iron which would take much longer to make than a steel forging, and the time occupied in its manufacture might probably have been very considerably reduced; but undoubtedly the advantage in output of the press in the case of such intricate forgings is much greater than in straightforward work. It is also well to bear in mind that the much greater

accuracy to shape and size of the forgings produced under the press, compared with similar work done under the hammer, effects a great saving in time and cost of machining.

Hollow forging is another class of work for which the press is much better adapted than the hammer. This is particularly the case in expanding operations for making hoops or drums, because the mandril and its supports stand up far better against the squeeze of the press than against the blow of the hammer, resulting in more expeditious and better work.

Economy in Working.

The principal factor in economy in working is the much larger amount of work that can be done in a heat under a good quick acting press than under a hammer, as there is not only the actual saving in time but considerably fewer heats are required to produce the same weight of forgings and consequently the expenditure in fuel in reheating is greatly reduced. Besides this, the steam consumption of a good modern press is barely half that of a hammer for the same output. Actual results over extended periods with presses have shown that in the production of solid, heavy forgings, such as shafts, the consumption of coal for steam production averages 3 cwt. (150 kilogrammes) per ton of forgings, but for general work the consumption may be taken at from 3 to 5 cwt. (150 to 250 kilogrammes) per ton. It is evident that with a hammer a great deal of useful work is lost in vibrations, and in a paper on Power Forging, with special reference to forging presses, by Gerdau & Mesta, published in the Journal of the American Engineer, July, 1911, it is assumed that this loss amounts to one third of the useful work, which is probably not over the mark. A calculation by the same authors gives the following results for equivalent powers of hammer and press.

Steam hammer, per stroke	8 lbs. (3.73 kilogrammes) steam
Steam, hydraulic press, per stroke	3.7 lbs. (1.68 kilogrammes) steam

An exact comparison is difficult to obtain, but the statement made above, that the steam consumption of a good modern press is barely half that of a hammer under average working conditions, is probably well within the mark.

When coal fired furnaces are used for heating the forgings, it is often possible, by means of the waste heat from the fur-

naces, to raise sufficient steam for working the press. This is generally more convenient and economical than using gas fired heating furnaces and independently fired boilers.

Absence of Noise and Vibration.

The press with its silent working and absence of vibration contrasts very favourably with the hammer which causes much inconvenience and often considerable detriment to adjacent furnaces and buildings and to the working of any machine tools in its vicinity. In many cases, the inconvenience caused by hammers to adjacent establishments has been so great that, on this account, it has been necessary to replace them by presses. Besides this, the foundation required for the press is very small and inexpensive compared with what is required for a hammer, and when the nature of the soil is unfavourable, this difference is accentuated. The working of the press is also much less detrimental to the tools, which can often be of cheaper construction and require less frequent renewals.

Capacity of Press and Equivalent Power of Hammer.

The following table, which gives the maximum diameter of ingot that each power of press is capable of dealing with effectively and the equivalent power of steam hammer, will be of assistance in making a comparison of the two methods of forging.

Diameter of Ingot.		Power of Press.	Power of Hammer.
Inches.	mm.	Tons.	Tons.
5	125	100	0.50
6	150	150	0.75
8	200	200	1
10	250	300	2
12	300	400	3
14	350	500	4
16	400	600	5
20	500	800	7
24	600	1000	10
30	750	1200	15
36	900	1500	20
48	1200	2000	40
60	1500	3000	80
72	1800	4000	120
84	2100	5000	
96	2400	6000	

From this table, it will be seen that the power of the press bears a fairly direct proportion to the diameter of the ingot, but the power of the hammer required increases much more rapidly, being nearly proportional to the square of the diameter or the sectional area of the ingot. For instance, for an ingot 24 inches (600 mm) diameter, the power of press is 1000 tons and the hammer 10 tons, but for a 48-inch (1200 mm) ingot, the power of press is 2000 tons and the corresponding hammer 40 tons, and consequently the heavier the work the greater is the advantage of the press over the hammer.

As stated above, for the heavier classes of work, presses have been used in many of the principal steel works for as much as 30 years, the power of such presses most generally used, up to 20 years ago, being from 2000 to 3000 tons, though during this period some much more powerful presses up to 10,000 tons have been put down for forging armour plate and special purposes. During the next 10 years, that is up to 10 years ago, owing to the increased size of guns and other forgings required, a good many presses of 4000 tons have been adopted. Luring the last 10 years, that is up to the present date, owing to the further increase in the size of guns and also to the larger forgings required for marine work, particularly turbine drums and spindles, the power of press required has increased correspondingly, 6000 tons being the power most recently adopted for the heaviest work of this class.

METHOD OF DRIVING PRESS.

To explain the development in the use of the press some mention must be made of the improvements that have been introduced in the method of driving.

The earlier forging presses have generally been driven by means of pumping engines working direct into the press cylinders, the working pressure being usually from 2½ to 3 tons per square inch (400 to 480 kilos per cm^2). For large presses this method gives satisfactory results, but it has never been used to any extent for presses of medium or small power for which greater simplicity and a higher speed of working, especially in finishing, are more essential.

Another method is to make the press purely hydraulic,

working it from an accumulator. For certain special work, such as piercing projectiles or billets for tube making in which a long stroke without any pause is desirable, this system is undoubtedly the best. For ordinary forging operations, however, for which a short rapid stroke is essential, this system has only been adopted to a limited extent and is applicable only to presses of comparatively small power.

The system that fulfills the requirements of forging best is the steam, hydraulic intensifier. For a good many years it has been used to some extent, but it is only within the last 10 years that it has come into general use and been adopted extensively for presses of small and medium power as well as for the heaviest forging presses. The advantages of the steam intensifier press are that, in its latest and best form, it is capable of fulfilling adequately all the requirements of forging. These include sufficient rapidity of action in all its movements, that is, the idle stroke when lifting the presshead and bringing it down to its work and the forging stroke or penetration. The idle stroke should be from 6 inches to 12 inches (152 mm to 305 mm) a second, according to the power of the press and the nature of the work, and the forging stroke up to 3 inches (76 mm) per second, according to the resistance of the forging. Also there should be no pause or dwell either when the tool first touches the work, that is, before the forging stroke commences, or at the end of the forging stroke; that is to say, the return stroke should commence directly the penetration is completed, any pause causing loss of time as well as chilling the forging. The length of the forging stroke is usually from 1 inch (25 mm) up to 6 inches (150 mm) or 8 inches (200 mm) in the case of very large presses, and the speed of such forging from 10 up to 50 strokes a minute, a total penetration of 60 inches (1500 mm) a minute being obtainable when the power of the press is well up to its work and the forging handled expeditiously. For rounding or finishing a forging, a very rapid stroke is desirable; a good intensifier press of as much as 6000 tons being capable of working up to 40 strokes a minute and smaller presses proportionately quicker up to 100 strokes a minute. With these speeds of working, an efficient control gear is desirable both to limit the forging stroke and also to prevent any

overrunning of the intensifier in case the load on the press is suddenly removed, owing to the forging or tool slipping or other accidental cause. So successfully has efficient control gear been applied to intensifier presses that they can be worked

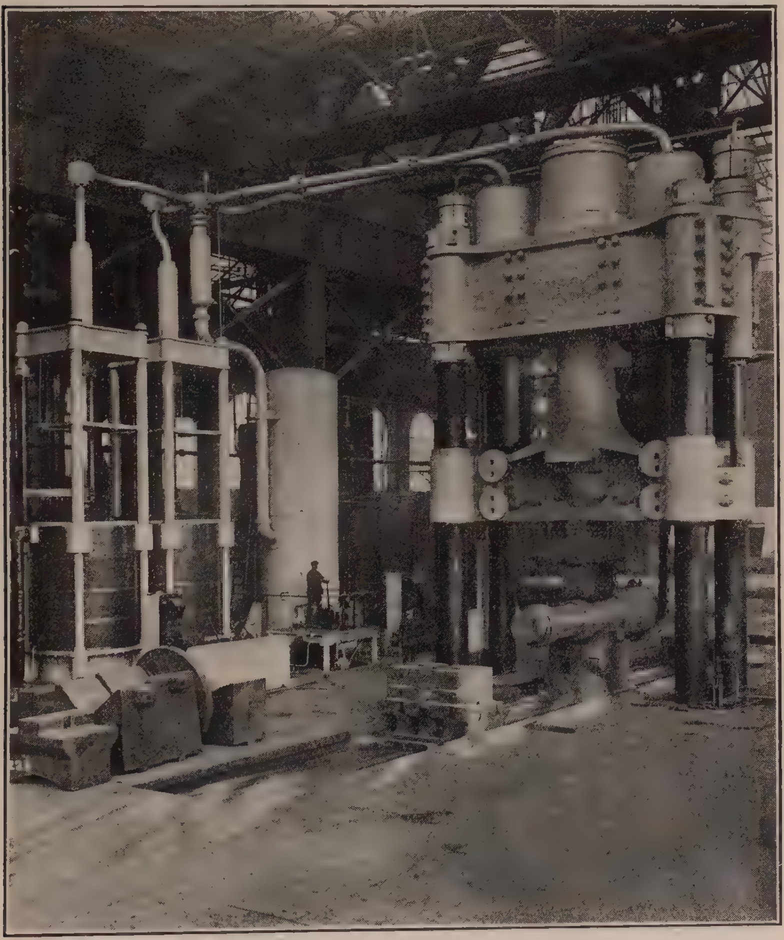


Fig. 1. Modern Forging Press of 6000 Tons Capacity.

quite safely and easily at the high speeds mentioned. Presses already constructed on this system range from 100 up to 6000 tons power, the larger presses giving proportionally equally as good results both in forging and in rapid finishing strokes.

FORGING OPERATIONS.

Fig. 1 illustrates an up to date forging press of 6000 tons power, engaged in forging a solid shaft. This press is driven by two intensifiers, arranged to work simultaneously or independently by means of catches on the handing lever. Working simultaneously, the intensifiers give a forging stroke of 10 inches (250 mm) and a speed of from 6 to 10 strokes a minute according to the penetration required. When short strokes for finishing are required, either intensifier can be used and the press can be worked up to 40 strokes a minute.

The full equipment for such a press, to enable it to deal advantageously with the various classes of work, includes the following:

Mandrel gear, giving the mandrel blocks a travel of about 30 ft. (9 metres) on each side of the press.

An extended base of sufficient strength so that the full power of the press can be exerted on the mandrill blocks when they are spaced at the maximum distance apart required for expanding work, such as turbine drums or gun jackets.

Manipulating gear for handling forgings without the use of a crane. This is particularly useful for certain classes of work, such as forging armour plate and turbine wheels and also in some cases for cogging ingots.

Transverse tool changing gear. This is useful for forging crank-shafts and similar work when it is desirable to change from flat tools to V shaped or swaging tools. This gear enables both top and bottom tools to be changed very quickly without taking the forging from under the press.

Turning gear for rotating the forging. The most convenient form is a self-contained electrically-driven gear, suspended from the crane hook. Fig. 2 illustrates such a gear. Preferably, this should be provided with a friction clutch which slips during the instant that the press grips the forging.

A press with the above equipment is suitable for practically all classes of heavy work and the following examples of forgings made under such a press may be of interest:

Fig. 3 represents a solid, turbine spindle forging, made from an 80-inch (2000 mm) octagon ingot weighing 116 tons, the finished weight of the forging being 55 tons.

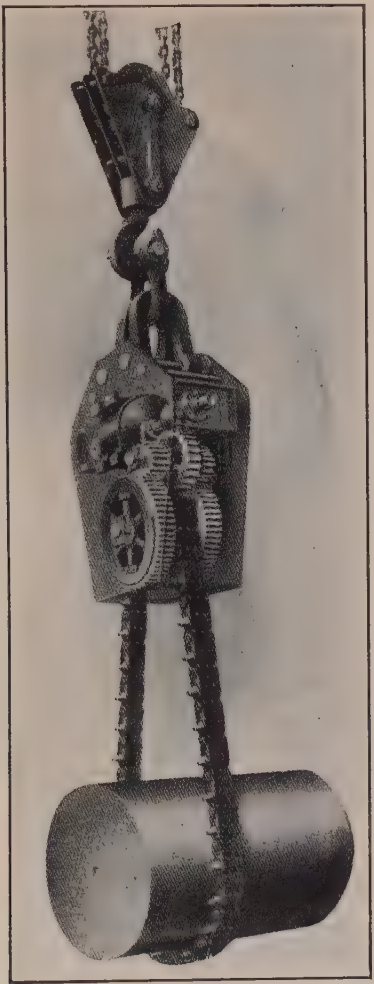


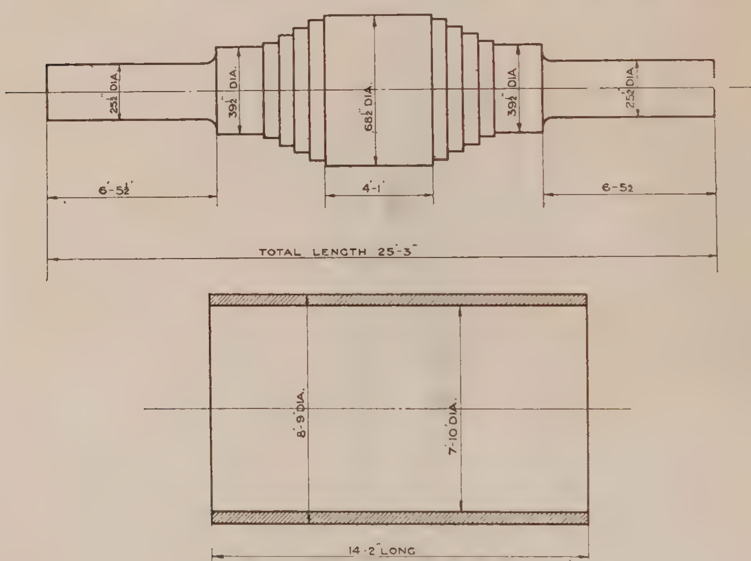
Fig. 2. Electrically-driven Turning Gear for Rotating Forgings.

Fig. 4 represents a turbine drum, forged and expanded, made from a 64-inch (1600 mm) dia. ingot weighing 85 tons, the weight of the forging being 35 tons.

Fig. 5 represents a hydraulic cylinder, forged and expanded. This forging required an 80-inch (2000 mm) ingot weighing 116 tons; the finished weight of the forging was 63½ tons and its rough machined weight as illustrated 42 tons. Its principal dimensions being:

Length, 14′-1″ (4200 mm).
Dia. over collar, 6′-6½″ (2000 mm).
Dia. of body, 5′-7″ (1700 mm).
Dia. of bore, 46″ (1170 mm).

For general forging work, all large presses, down to 2000 tons power, should be fitted with mandril gear as that greatly



Figs. 3 and 4.

facilitates the work under the press and the handling of the forgings. It can also be used conveniently for changing the tools when transverse tool changing gear is not included in the equipment. For medium sized presses of from 1000 to 1500 tons, a simple form of mandrel gear is often desirable and is generally well worth the comparatively small additional cost.

Amongst the special classes of work for which presses have recently been adopted may be mentioned the following:

Tyre Forging.

For slabbing and punching tyre blanks, presses have been adopted with very satisfactory results. Apart from the economical side of the question, it has been proved that tyres forged under the press give distinctly better results under test than the same steel forged under the hammer, and with the very high tests now called for in such material, this is very valuable. The power of press that has generally been used for this purpose varies from 1200 tons to 2000 tons, but in one

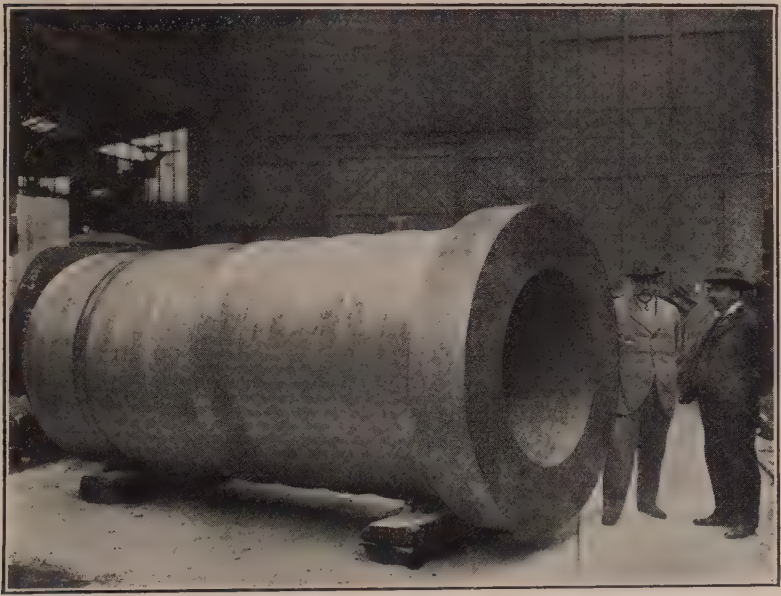


Fig. 5. A Forged and Expanded Hydraulic Cylinder after Rough Machining.

instance a press of 5000 tons has been put down for this class of work. A press of this power can slab the largest tyre blank at a single stroke and so is capable of a very large output. A 1200 ton press, without any mechanical appliance for handling the blanks, has produced as much as 40 tons of waggon tyres of 200 kilogrammes apiece in an 11-hour shift, and 48 tons of locomotive tyres of 600 kilogrammes apiece in the same time. More power is, however, preferable for this class of work, and recently presses of 1500 and 2000 tons have been more generally

used. The most recent instance is a 2000-ton press fitted with a manipulating gear and rotating table which is illustrated and described in the "Engineer", pages 534 and 539, Dec. 4th, 1914. The rotating table, which is mounted on a slide, enables the piece to be carried under the press and slabbed very rapidly by successive strokes, and the manipulating gear centres the blank so that the top punch can be entered correctly and then lifts it on to the bottom punch, ensuring a hole truly central and without the formation of any fin. This gear entirely dispenses with any manual work in handling the piece under the press and also greatly increases the output.

After the slabbing and punching, the tyres are frequently passed straight on to a roughing mill before the final rolling in a finishing mill, but in some cases, a second press is used for becking or expanding the tyres before rolling. This has the advantage of closing the material which has been stressed to some extent on the periphery by the slabbing. For this process, a press of from 500 to 800 tons is generally used and is capable of an output of from 40 to 50 tons in a shift.

Disc Wheels.

During the last few years the use of disc and Schoen wheels has extended very greatly and consequently the forging of these is a matter of very considerable importance. For the forging of these, two methods have been adopted. One method is to use a press of sufficient power to forge the wheel in one or two operations, the top tool covering the whole surface of the wheel in the final squeeze. This necessitates a very powerful press generally of about 8000 tons.* By the use of the quick acting press, such wheels can, however, be forged under a press of much smaller power. In several cases, a 1500-ton press, fitted with a rotating table for revolving the work, has been used. In this case, the top tool, which is about 12 inches (300 mm) wide, is made to the section of the wheel so that, as the blank revolves, the successive strokes of the top tool on its surface shape the forging and spread it over the whole surface of the bottom circular tool. This method effects a great saving in the first cost of the plant required for such work.

* Ref. J. H. Baker, Forging Car Wheels, Proceedings of Engineers Society of Western Pennsylvania, Vol. XXV, pp. 165-190, 1910. Also Schoen Wheels, Iron and Coal Trades Review, Vol. 44, pp. 1124-1127.

Axle Forging.

In the past, axle forging has been done chiefly under hammers, it being easier with hammers to get rid of the scale and consequently to obtain a better surface. In several cases recently, quick acting presses have been used for the first process of cogging the ingots and forging the axles roughly to shape, and as some governments and many railway companies require in the case of pressed forgings only half the sectional reduction that is called for when the ingots are cogged in a rolling mill or under a hammer, the use of a press for this purpose is additionally advantageous. The output of an 800-ton press in cogging from the ingot and rough forging is from 20 to 30 tons of axles in a shift.

For finishing axles, the difficulty of the scale, mentioned above, presents itself, but this has been to a great extent got over by the use of bracken or other suitable substance for detaching the scale, and by making the tools sufficiently wide to prevent the scale which is detached from being pressed in. The finishing tools have generally three grooves about 12 inches (300 mm) apart, and to obviate the objectionable side stresses that would come on the press when finishing in the outer grooves, an arrangement has been adopted of mounting the tools on slides, worked by power, so that the top and bottom tools move simultaneously and the grooves in use can be brought instantaneously to the centre of the press.

For the first process of cogging and rough forging, the use of presses has proved very advantageous, and it seems likely that their use for finishing axles may also extend.

Cogging Ingots.

Many presses have already been put down for the purpose of cogging ingots for special manufactures, the powers of press generally used being from 600 to 1200 tons. Trials on special steels have proved that much better results are obtained by cogging such material under the press than by hammering or rolling. In the case however of steel of ordinary composition but which is required to be of specially close and uniform texture, as for instance for the manufacture of material which has to be drawn, it is found that cogging under the press, prior to the subsequent processes of rolling and drawing, produces a very great improvement in the texture of the steel. So marked

is this improvement that in some cases a comparatively small reduction under the press in the original sectional area of the ingot proves sufficient to give the desired result.

Shell Forging.

For the purpose of forging externally armour piercing shell up to the largest calibres at present required, quick acting presses of from 1200 to 2000 tons have been used to a considerable extent. For the processes of piercing and drawing which require a long continuous stroke, purely hydraulic presses worked from an accumulator are much more suitable.

General Forgings.

For the production of engineers' and other general forgings, an up-to-date, quick acting press has really no competitor. Its general advantages over the steam hammer have been already enumerated, but it is only by experience of its capabilities in actual use that its superiority can be properly realized. For the manufacture of forgings of simple form when large quantities are required, dies can be used and in many cases the forging can be produced by a single stroke of the press. Dies can also often be used in the case of forgings of more complicated form, but then it is generally necessary to forge the piece roughly to shape before using the dies to produce the exact shape and dimensions required. This point is particularly mentioned because die forging can be done much more advantageously under a press than under a hammer, providing there is a fair body of metal. Generally speaking, it is only quite small forgings and especially those of a very light section which are best made under a hammer or drop stamp. With a press, the tools and dies can be of a cheaper and lighter construction and they last much better than when used under a hammer.

For many special manufactures requiring a considerable number of similar forgings so that special tools and dies can be provided, the use of high speed presses has proved extremely advantageous. Amongst such applications which have already been made, the following may be mentioned.

For locomotive and railway works, for general small forgings including coupling and connecting rods, presses of 150, 500 and 600 tons.

For stamping crossheads and other forgings required for boiler feed pumps, a 600-ton press.

For stamping field-gun carriage forgings, a 500-ton press.

For bridge and structural work, for such work as stamping link ends, presses of 150 and 300 tons.

For shipbuilding works, 300- and 500-ton presses.

For anchor forging, an 800-ton press.

For forging well boring tools, an 800-ton press.

For the manufacture of tyres of a flat rectangular section for road vehicles, for the first process of slabbing and punching and for the second process of expanding or becking, presses of 400 tons of special construction.

An interesting example of making special forgings is given by Bruce Browning in the American Machinist, 1909, under the heading "Hydraulic Forging". He describes the manufacture of hubs under a 150-ton quick-acting press. These hubs are made from a piece of round stock. A wide external flange is first forced up in the centre and they are then pierced and the upper end cupped in special dies, the production being 100 hubs in 10 hours.

Apart, however, from special application, presses of small and medium powers are beginning to be used to a very considerable extent for general engineers' forgings both in forges and in engineering works. The powers that have so far been used for this purpose in engineering works range from 150 to 800 tons and in forges up to 1500 tons, and it can be safely stated that such presses have proved generally very profitable. In an engineering works, it is often preferable to have the facility for producing the smaller forgings required especially when repair work is undertaken, and the much wider range of work that can be done under a press than a hammer is a substantial advantage. In a forge, it is desirable to have a sufficient proportion of presses of medium power as it is generally possible to keep such presses more uniformly employed than the heavier presses, and the production is naturally more economical when the power of the press is proportional to the size of the forging.

In several cases, 300-ton forging presses have been installed in steel rolling mills for doing general repairs, and they have proved exceedingly serviceable for this purpose in enabling

breakdowns, which are liable to occur with such machinery, to be dealt with very promptly on the spot and thus greatly reducing the stoppage of the mill or other plant.

Another application which is of interest is the use of quick acting presses for the manufacture of iron from the puddling furnace. With presses of sufficient rapidity of action, very satisfactory results have been obtained both in quality and output, the powers of presses generally used for this purpose being 400 and 500 tons.

For naval repair ships, forging presses of a specially compact construction have been used, generally of 150 tons power. The advantages of a press for this purpose are that, unlike a hammer, its working causes no inconvenient vibration or damage to the structure of the ship, and that it is capable of dealing with repairs of a far more extensive character.

In conclusion it may be stated that the superiority of presses over hammers for the heavier classes of work has been recognized for the past 20 years and their use frequently adopted, but within the past 10 years, owing largely to improvements in construction and particularly to increased speed of working, their use has become much more general, and it is only within this latter period that presses of medium and small powers have proved a practical success and have begun to be freely adopted.

Forging presses of all powers, and particularly of medium and small powers, will undoubtedly come into much more extensive use in the near future as foreshadowed by the advance made during the past 10 years, and more especially because the increased speed of working that has been attained opens so much wider a field for their useful application.

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Note.—The discussion following Paper No. 117, "Forgings from Early Times until the Present", by C. von Philp, applies also to Paper No. 116.

Paper No. 117

FORGINGS FROM EARLY TIMES UNTIL THE PRESENT.

By

C. VON PHILP, Mem. Am. Soc. Mech. Engrs.
South Bethlehem, Pa., U. S. A.

By forging, the author means the process of working iron, steel or softer metals into some definite shape when they are in a more or less hard or pasty condition.

The different methods of producing forgings treated in this paper are:

Hammering,
Pressing and Squeezing,
Extrusion,
Die-Casting,
Bending.

HAMMERING.

By this method, forgings are shaped by a series of successive blows. The first actual forgings were made in this way, on anvils, by manual-worked hammers and ordinary blacksmith tools.

The steel was usually produced in the knobbling fire, by stopping the process of knobbling before the metal in the fire had reached a state of wrought iron. By this method, quite large forgings were made—like good-sized anchors, etc. This method, however, is nowadays almost solely used for repair work and for producing smaller special articles, since forgings of larger size, or greater quantities of identical pieces, require better facilities in order to be made in an economical way.

The first step in this direction came with the introduction of the trip-hammer, in which the sledge-hammer was substituted by a hammer-head, operated by gravity and lifted by means of

a water-driven cam wheel. As larger and larger forgings came in use, more powerful hammers were required, and the trip-hammer was superseded by the steam-hammer.

With the development of these hammers, the size of forgings that could be made was greatly increased. The demand for very large forgings, especially for very large size shafts, guns and armor plates, led to the increase of size of these hammers, until finally culminating in the steam-hammer built by the Bethlehem Steel Company some twenty-odd years ago. This hammer had a 125 net tons falling weight, and a stroke of twenty feet. It was provided with a steam valve gear, so that a child could operate it, in contrast with those used in some European plants, where quite a crew of husky men, sometimes as high as five or six, were on the platform. This enormous hammer was used chiefly for armor plate, and also for large size shafting.

Die Forging.

It was found at an early date that a great number of forgings could be very economically produced with the aid of dies under hammers. The use of this method depends very much on the number of identical pieces to be made, as the cost of dies often is very high.

Another factor that governs the use of this method is that forgings produced in dies are uniform and of more exact dimensions than those made on an anvil; hence they will require less machining, and for many purposes the forgings can be used in their rough state, or after only superficial grindings.

Even for a rather small amount of forgings, die forgings may be economically made by use of cast dies, or by preliminarily shaping the piece under hammer and on anvil, and only giving it a neat finish and more exact dimensions by inserting it in the die and striking it a few blows under the hammer. This process developed the board drop hammer, which is still in use in the manufacture of small arms and similar articles. For larger forgings this hammer was superseded by the steam drop hammer.

This art of forging has developed to such an extent, that all kinds of intricate forgings are now produced that could never be thought of when the old method was employed.

Swaging Process.

In the manufacture, the general rule is, that, if a certain piece can be produced cold, not to heat it. We find this in the cold swaging process, where material is drawn out to a fine point or reduced in cross-section. This is performed in high-speed forging machines, where the work is subjected to a large number of blows by dies shaped to the desired form. This process is especially applied to the reduction of rods and tubes.

FORGINGS REDUCED BY PRESSING AND SQUEEZING.

It was found that hydraulic presses could be used for continuous forging in the same manner as a steam-hammer, and they have rapidly replaced the latter, especially for heavy forgings, as the effect of the hammer on a massive forging is more superficial than that of the press, which works the material right through to the center of the forging.

Another advantage in the press forging is that material that can not stand a hammer blow will to advantage stand the pressure from a press.

Still another advantage of the press is that the destructive vibrations from the impact of the hammer, to machinery and buildings, are eliminated.

This method of producing forgings has greatly developed, and owing to the high speed of the modern forging presses, these can now compete with the hammers in producing forgings of even comparatively small size. (Fig. 1.) Early presses of this nature received their driving force from accumulators, later on by direct pumping by means of steam intensifiers, where a part of the energy to be supplied to the press came from the fly-wheel of the pump. These machines were of the highest economy at the time, but still not of the highest economy obtainable.

Forgings of a better quality could be made under these presses than under hammers, and it was also found that hollow forgings could be produced in a feasible and economical manner.

Very large-sized presses of this nature are built, for example, at the Bethlehem Steel Company's plant, where they have been running for about twenty years. One of these, the

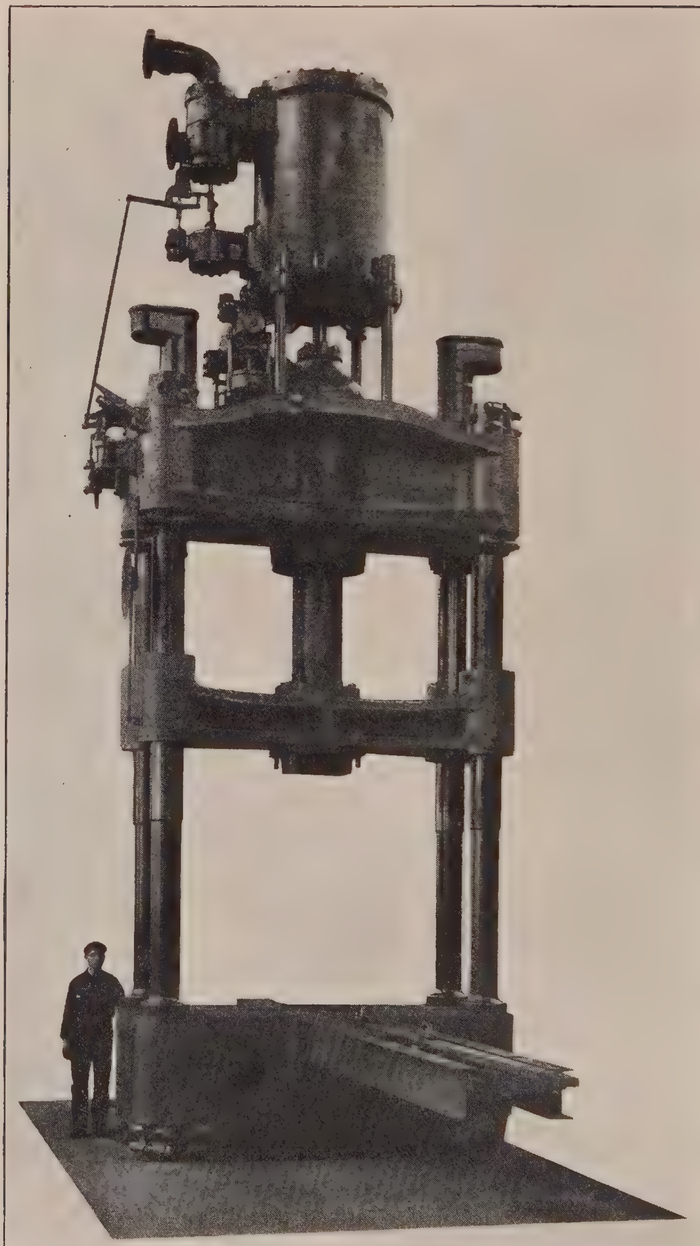

Fig. 1.

largest press of its kind, has a capacity of 15,000 tons and a pumping capacity of approximately 16,000 hp.

The most modern development in the forging line has been in die forging presses.

It has been found that, with modern machinery, the time eliminated enters greatly into the possibilities of changing shapes of metals.

In order to get the maximum economy out of presses of this kind and also to be able to get sufficient speed, it is necessary to have accumulators of large capacity, pumps for supplying same, and of great importance are the hydraulic valves through which this water is supplied to the machines. The author has probably produced the largest sizes of valves for this purpose, that is, up to 16 in. diameter free opening. In the running of these presses, and to produce the highest speed desirable, it was found necessary for the sake of economy, etc., to have a supply of low-pressure water to fill the press moving the platen, upper or lower as the case may be, by means of separate cylinders used and operated for that purpose. By following this method, 100 or more strokes per minute are obtainable.

The modern forging press, be it die forging press or flat die press, has made possible endeavors like the New York Subway, which could hardly be operated at the speed it is without the solid forged car wheels.

These presses are made of very large capacities, up to 10,000 tons, and more, with productions averaging 700 to 800 lbs. of forgings per minute. (Fig. 2.) By far the largest proportions of forgings manufactured in this manner are used for railroad cars.

One advantage of the hydraulic forging press is that dies for the same can be made of gray iron instead of steel, which must be used for drop-hammers.

Another way in which forgings are produced by squeezing is employed in the rolling mill; for example, in the making of structural shapes, thinner armor plates, car wheels, tires for locomotive wheels, crushers, etc. The latest development in this class of forging is found in the producing of long pipes of large diameter. This is accomplished in the pipe-making machine built by the Bethlehem Steel Company, by bending a plate,

welding the joint and afterwards giving the weld a smooth finish by rolling.

Forgings produced by upsetting and heading (for example, bolts and rivets) are being made chiefly in dies by power-driven

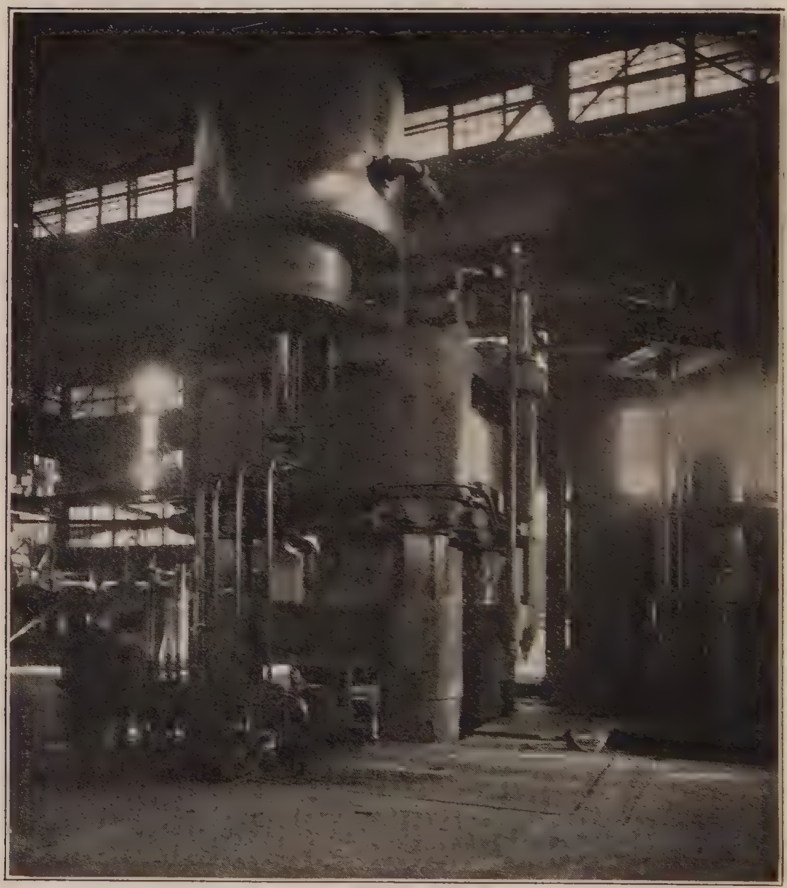

Fig. 2.

upsetting and forging machines. (Fig. 3.) Forgings of this nature can now be made to advantage in hydraulic presses, which adapt themselves very well for this purpose, as in these machines forging can be done in two or more directions. For

example, the machine built by the Bethlehem Steel Company which is the latest development in this line.

EXTRUSION OF METAL.

By extrusion of metal is commonly meant the process of pressing metal, in hot or cold condition, through a die or opening of the size and shape desired. The metal is usually heated, but some of the softer ones are also worked cold. This, however, takes considerably more pressure, compared with what is required when the metal is heated. On the other hand, the metal by being worked harder is improved in strength and structure. Even when extruded at high temperature, the metal, being compressed, gets a finer grain with a higher tensile strength.

Another advantage of this method is that intricate cross-sections can be given to the material, and the articles produced get a very neat finish and are so uniform in size that the variation is not more than one-thousandth part of an inch, or even less. For this reason, the extruded metal is used without any machining. This method is used in the manufacture of pipes and wires of lead, miscellaneous shapes in brass, shrapnels of steel, valves for automobile engines of high grade steel, rods, etc.

DIE CASTING.

Still another forging method, though a new-comer and one that it has taken quite some time to develop, is the forcing of softer metals than steel into dies of miscellaneous shapes. This is commonly known as die casting, hot brass die forging, etc.

By this method, forgings of very accurate shape, sharp contours and finish are obtained. Even holes produced in these forgings are so true that they are just as good as reamed holes.

Die castings, as previously mentioned of extruded metal, get a very high tensile strength and a fine and close grain; this on account of the pressure to which they are subjected. Among products manufactured by this method can be mentioned carburetors and instruments.

BENDING.

Bending, as a forging process, was mostly employed for flanging boiler heads and similar articles. Its use became more

and more general, and when the steel freight car made its appearance, it was found that instead of using structural shapes, special forgings made a more substantial and economical product. Large dies of cast iron are used for this purpose.

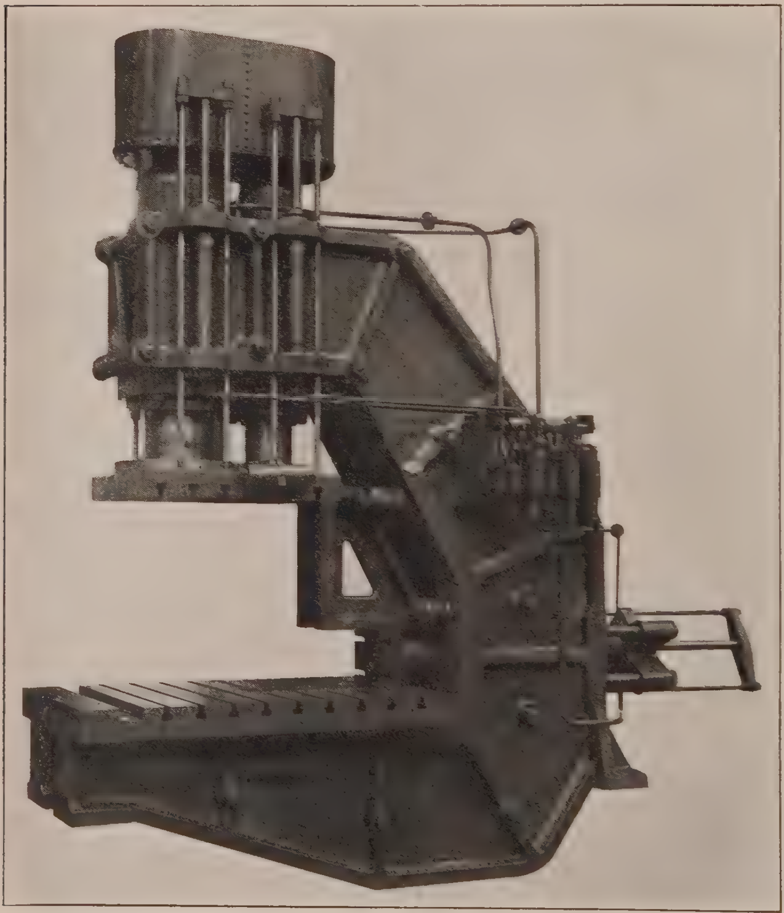

Fig. 3.

It is also largely used in the ship-building trade, where flanging is done more or less progressively with the aid of sectional dies; as, for instance, in the sectional flanging press, and also in the long keel benders, which are made up to six hundred

tons capacity, where plates thirty feet in length can be bent in one stroke. (Fig. 4.)

Another kind of bending process is the one used in bending armor plates, where dies are of prohibitive cost on account of the many different shapes needed. Here, blocks and wedges are used to produce different shapes, without which one die for each piece would be necessary.

Bending and flanging, as a rule, are nowadays done under hydraulic presses, as mentioned above, often of extremely large sizes and capacities. (Fig. 5.)

HANDLING OF FORGINGS.

An important factor in modern forging is the handling of the work, and this is the more important, the larger the forgings are.

An up-to-date plant for general forging is equipped with a crane or cranes for serving the furnaces and the press. This crane may be a jib with a chain block for small plants, or an electric overhead traveling crane for larger ones.

To be able to handle the work with the crane, it is, before being removed from the furnace, fastened in a chuck by means of heavy screws, and balanced by weights placed at the end of a bar extended from the chuck. For drawing down, and similar operations, where the work has to be turned during the forging process, use is made of a special turning rigging (Fig. 6) suspended from crane hook. This rigging consists of an endless, straight link chain revolved by an electric motor through suitable gearing. The whole apparatus is self-contained and is attached to the crane hook by a flexible connection, thereby relieving the crane from undue strains. The chuck, with the work, is placed on the chain and turned by revolving the chain.

Another device which, especially for larger forgings, is necessary for the economical handling of the work and tools is the "manipulator". This consists of a bar, operated by hydraulic or other power, and sliding on the top face of the press base. The press base is, for this purpose, extended on one or both working sides. (Fig. 1.)

In hollow forging work of large diameter, such as tires, one

of the anvils is, by operating the manipulator bar, slid outside the press to permit the placing on it of the forging bar with the work, by means of the crane. The work is thereafter brought under the press by the anvil, and when forging is ended, the work is in the same manner again brought in reach of the crane. This device is also of great advantage in hollow forging work of

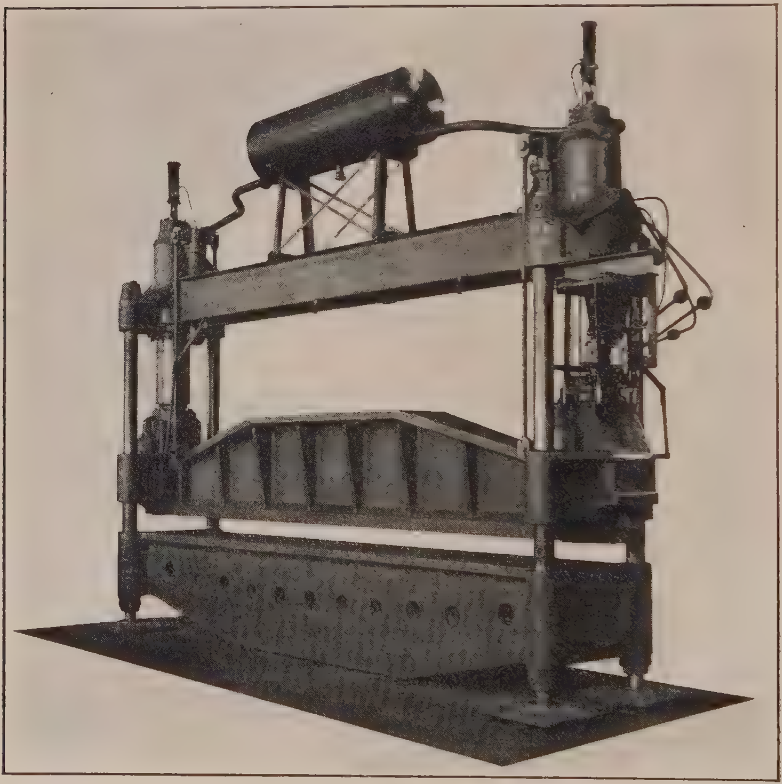

Fig. 4.

great length, as shafts, etc., where both the anvils are manipulated for feeding the work through the press.

The manipulator is also of great help for changing of anvils and dies, as it enables them to be brought in reach of the crane. It might also be used for stripping purposes and in straightening operations.

HEATING OF FORGINGS.

As a last thing, although of the utmost importance, may be mentioned that, in heating the material, oxidation of metal should be avoided. Whatever fuel is used in the furnace, it must be combusted before it comes in contact with the forging.

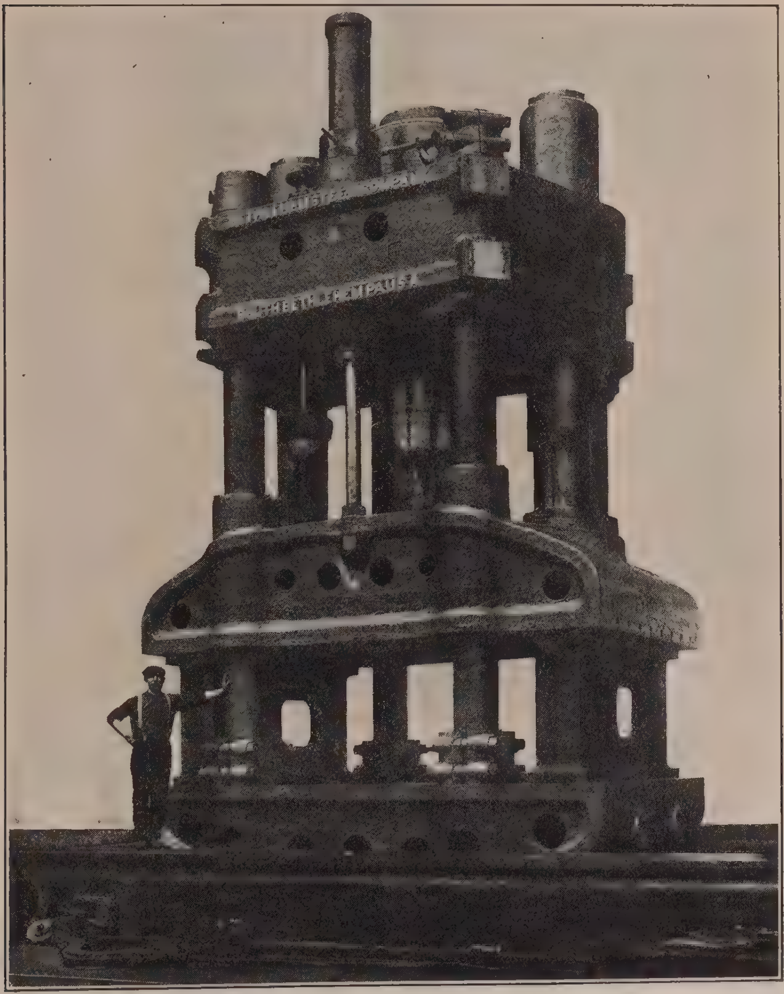

Fig. 5.

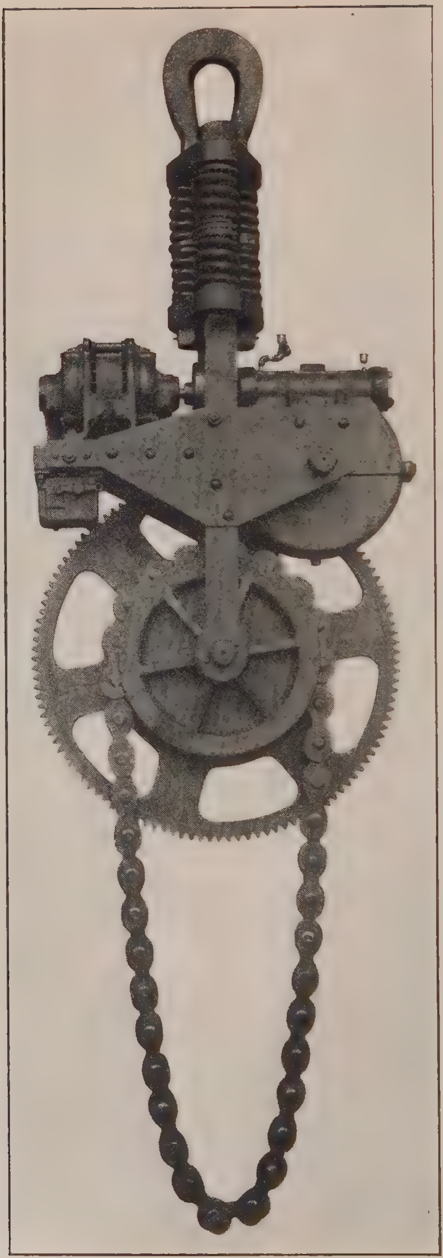

Fig. 6.

DISCUSSION

The Chairman, Mr. G. W. Dickie,* Mem. Am. Soc. M. E., in opening the discussion stated, that in his early days there had been very little in the way of machine forgings, while at present it was often cheaper to remove excess material in the machine shop than by careful forging. Thus much of the skill of hand forging had been done away with. Mr. Dickie

In the exhibits in the Swedish Building at the Exposition it would be seen that when iron gets into the hands of a Swede, it is in the hands of a master.

When the first vessel of the new navy was built here in 1888, it was necessary to have forgings for the shafting made by Krupp, in Germany, while at present the United States equals all other countries in forgings for battleships, both shafting and armor plate.

Forgings are now being done more by pressure than blows, which enables work to be done which could not be accomplished before the advent of press forging methods.

Mr. W. A. Doble,† Mem. Am. Soc. M. E., stated, that in the art of forging, the great advantage of the press over the hammer is that the force is distributed over the mass, while in the hammer it is more of a surface blow. The ends of a shaft overlap in hammering, making a cup shape, with resulting internal stresses. Mr. Doble

Some years ago, they had made some rollers for Mr. Dickie for the Lick Observatory. As they came from the hammer, practically all of them were ''piped'', due to the fact that, in forging from the square to the round form, the forging was rolled under the hammer, producing a hole in the center.

This method has been used in producing hollow ingots. Rolling produces a cross movement of the outer particles.

The expense connected with the forging press, which has retarded the development of the process, has been in the installation of pumps and auxiliaries rather than in the press itself.

The influence of high-speed steel on the forging art has been greatly felt, for by its use metal is very quickly removed in the machine shop and less care is necessary in forging.

The art has also been affected by the production of intricate steel castings, materially reducing the necessity for more finished work from the forge.

Electric and oxy-acetylene welding has also had its effect. Parts are made separate and welded together.

Heavy forging has not advanced as rapidly on the Pacific Coast as in the East. There is not the demand here for heavy forgings for guns and armor.

He expressed the opinion that all steam hammers in California could be profitably scrapped and replaced by high-speed forging presses.

* Consult. Engr., San Francisco, Calif.

† Chief Engr., Pelton Water Wheel Co., San Francisco, Calif.

Mr. Langille.

Mr. H. B. Langille‡ asked for information as to the experience of any of the members with die casting.

A member, who stated that he did not wish to be quoted, told of the making of the parts of an invisible hinge at a plant in Brooklyn.

The limitations of the process were in the nature of the metal which must be used. This must be soft and worked at high temperature, being squirted under the pressure of a plunger into cast iron dies, no finish being necessary. The possible materials were limited by the flow under pressure.

He had also had experience with die castings in a circulating pump for his automobile. They had not been a success, as the hard water ate out the parts, and two sets of castings had been replaced. Finally he had substituted brass castings, which had proved satisfactory.

‡ Instructor, College of Mechanics, Univ. of California, Berkeley, Calif.

Paper No. 118

MACHINE SHOP EQUIPMENT, METHODS AND PROCESSES.

By

H. F. L. ORCUTT
Rowington, Warwickshire, England

A review of the subject of this paper must necessarily include conditions both in Europe and the United States. Although the undoubted home of the newer engineering methods is in the United States, that country cannot claim a monopoly in "modern" shop practice. There are certain conditions prevailing in American machine shops which are a direct hindrance to the full realization of the modern shop. In Europe there are in operation influences and conditions working distinctly to the advantage of the European manufacturer.

A gradual but certain extension of the so-called "American" methods and processes is spreading over industrial Europe. That is in regard to purely mechanical operations, the division of those operations, the use of types of machines for special classes of work and the adoption of appliances and tools in connection with definite types of machines. The old-fashioned European "general engineering" workshop still survives in many places and its "methods" still largely influence and even control some of the newer establishments in their processes and standards of workmanship. In such shops the words "interchangeable," "standards" and "accuracy" are glibly used but the actual thing itself is not carried out except in a surprisingly few establishments. The same remarks apply to more shops in America than is commonly admitted.

Undoubtedly the European manufacturer is gradually coming to understand the "cheapness of accuracy" where quantities are concerned. It is not however much understood in any country how important it is to economical production to or-

ganize and fix "standards" even where small quantities are produced, whether the work be of a light or heavy nature.

In America there is undoubtedly a growing tendency to push for output at the expense of high quality. Many manufacturing establishments organized for the production of large quantities can rely on the public taking articles which are certainly good value for the money, but which have short life and are not of the highest standard. There is a tendency to seek for quick and rapid output, giving less attention than formerly to fundamental preparation necessary to secure accuracy and durability. There are not enough of the old type of American mechanics in the States to meet demands. The mechanic whose brains and handiwork made the small arms, the sewing machine and the typewriter of to-day possible, is a scarcity in the American motor-car industry. As contrasted with this it may be stated that the high quality of the European motor car or automobile is chiefly produced by the aid of the high-grade, old-fashioned engineer who did his individual work well and thoroughly, and who is now assisted by American designed machines.

A contrasting condition, to the distinct disadvantage of the States, is found in the comparatively large number of good workmen available in Europe. Methods, systems, organization, planning, scientific management, motion studies, time studies, are much to the front in America. Engineers, men to carry out these ideas, who have practical mechanical training, are relatively scarce. Workmen with fine touch and deep knowledge of the highest mechanical accuracy are not trained as they used to be, and in numbers grow less and less, compared with the enormous strides made in "output." In European engineering establishments there is still a comparatively large sprinkling of the old-fashioned, well-trained mechanic. He is not, as in the States, over-run by enormous numbers of unskilled men called for by the "large quantity" demands that exist in the U. S. A. On both sides of the Atlantic there is the same indifference with employers, with educational bodies and particularly with parents, to the necessity of the thoroughly practical training absolutely necessary to produce the requisite numbers of skilled men to carry on our manufacturing with economy and efficiency. All are after the dollar with the least

effort, seeking the leisure and pleasure of retirement from work in the quickest possible time. The working man by strikes and agitation is trying to increase his wages without making extra efforts to increase his efficiency. Well-to-do parents are trying to push their sons into positions of responsibility and high salaries without giving them the training absolutely necessary to make intelligent and wise managers.

IMPROVEMENTS IN MACHINE TOOL DESIGN.

There has been comparatively little progress made in the last 20 years in distinctly new "types" of machine tools. Much progress has been made in detailed development. Actual new types of machines are rare, and the same may be said of mechanical operations. Detailed alterations are endless and important. The ordinary mechanical operations and types of machines on which these operations are performed are so well known that they need not be reviewed. It will be well however to draw attention to some of the more important features of latter day development. The details to be reviewed have been a step by step growth during the last 15 years. They are not always appreciated by those who have under consideration the purchase of machinery and are not always used to the full benefit by manufacturers in reducing costs and increasing output.

Among the most important improvements of machine tool design the following may be mentioned:

1. Single pulley drive.
2. Change gear boxes.
3. Independent motor drive.
4. Ball and roller bearings.
5. Speeding up of idle movements, quick power returns and automatic movements when not cutting.
6. Provision for cutting and cooling fluids.
7. Provision for better lubrication.
8. Increased precision.
9. Chain drive.
10. Rigidity in design.

No one factor can be mentioned which has had so much influence on the design of the modern machine tool as the introduction of high speed steel. To get the full benefit of this marvellous material it has been necessary to alter details in nearly the whole line of machines that are used in the ordinary

processes of production. A machine tool in which high speed steel can be used to full advantage should be designed and constructed to meet requirements in some respects revolutionary compared with the older features of construction.

Higher cutting speeds must be maintained. Great rigidity is necessary. Feed mechanisms must be revised to give greater range; and higher velocities, more power and positive drives are essential. Increased accuracy is desirable to withstand greater wear of rapid motions. Especially, attention must be given to supply and control of cutting fluids. A machine tool which does not possess features of design and workmanship covering the above details should not be purchased, if the full benefits of the use of high speed steel are desired. Yet it is astonishing how many machines are made and sold with some or all of the features mentioned entirely wanting or only half developed. And it is also astonishing how many machines are in use in which these features are well worked out, and still little or no benefit derived from them by their purchasers. In view of the certain demonstrated efficiency of high speed steel, it is wonderful how many machines are being used today (even with cutting tools made of high speed steel) with feeds and speeds that were taught in our shops 30 years ago. There is a reason for this condition, which will be dealt with later on, that has very little to do with the design or construction of the machines. At any rate the machine tool makers know of the possibilities in rapid production due to the use of high speed steels. Some of the improvements made will be briefly mentioned.

The Single Pulley Drive.

This is not a "luxury," as considered by many, and is a necessity to rapid production except in cases where only very light cuts are called for. It makes possible a very strong belt pull at all speeds. Combined with a good gear box, it covers a large range of speeds. In most cases countershafts can be dispensed with as well as belting with its uncertainties and costs of upkeep.

Feed Change Gear Boxes.

These usually take the place of groups of small cone pulleys and numerous belts. They give positive motions, quickly altered, and an increased variety of feeds.

Independent Motor Drives.

They are usually more practically applicable to the larger machine tools than to the small types. They assist very much in the locating and grouping of heavier machinery, making possible the most economic and methodical arrangements of plant regardless of main shaft drives. They are not of much value usually to small machines, which are as a rule arranged in groups which can be driven from a common motor and line shaft. The expense of individual motor drive is hardly warranted in small machinery. The "patch-work" design of many machine tool makers in the application of motor drive has certainly done much to discredit its extensive use.

Ball and Roller Bearings.

These have been introduced in many places in machine tool design making it possible to run at high speeds for long continuous service. They have helped the designer to meet difficulties hard to overcome in any other way. The ball bearings which have reached so high a state of perfection in the motor car will be used still more extensively by the machine tool designer. The roller bearing also is finding its way, and is replacing the ball bearing in many cases.

Speeding up of Idle Movements.

This feature of machine tool construction has not had the attention it deserves. Its importance has not been pressed home to the user, due largely to conditions of management and the lack of efficiency studies. It is quite clear that as actual cutting speeds increase, the time occupied between the cuts becomes relatively of much importance. When machine cuts can be made 4 and 5 times faster (even more) with high speed steel than with ordinary carbon steel, it is clearly obvious the next stage in which "machine times" can be reduced is in the manipulation and handling of the machine. But comparatively few machine tool makers have perfected designs for rapid returns, accelerated speed motions when no cuts are on and quick power motions of work tables. Yet they are of just as much importance as it is to have a jig designed so that work can be rapidly fixed and removed. The ideal is entirely automatic movements of the work table and tool holders at the fastest possible speeds when machines are not cutting.

Provision for Cutting and Cooling Fluids.

It is astonishing how few machine tools are properly arranged for the supply and control of an ample quantity of cutting fluids, either oil or compounds. In spite of the common knowledge that cuts can be increased by a large percentage by the use of a large volume of fluid (See Taylor's paper on the Art of Cutting Metals) manufacturers continue to supply machine tools with little or entirely inadequate provision in this respect. Looking through the catalogues of the lathe and milling machine makers one is struck with the number of machines with no provision whatever for this important feature. A lathe, drilling or a milling machine is really difficult to find properly designed in this detail.

Grinding machine makers are about the only ones who have thoroughly dealt with this feature.

Lubrication.

This is now given more attention than formerly. Good provision is necessary in the modern machine with high speeds, close fits and complicated mechanisms.

Precision.

Undoubtedly the general trend is towards better workmanship. High speed steel has forced improvement in this respect. A machine with poor workmanship cannot stand up to strain of rapid motions, high spindle velocities and heavy bearing pressures.

Rigidity.

This is still a much neglected feature. Good work cannot be produced rapidly on flimsy, chattering machines. It is not usually appreciated that massive construction is essential to rapid output in many cases even when comparatively light cuts are taken.

Chain Drive.

This is a detail that should not be overlooked in the modern machine. Its efficiency and practicability are proven. It is positive, long lived, stands high speeds, is cheap and silent. It will stand duties not yet generally appreciated by machine tool makers.

These improvements in design of standard machines are largely due to necessity or natural causes following the intro-

duction of high speed steel. They are well developed in detail but not yet extensively adopted. As a matter of course they are more commonly in use in the States, where labor conditions force manufacturers to adopt, more rapidly than in Europe, those devices which directly reduce labor costs. It is not necessary in the States to give as much consideration to scrapping old plant, and general charges on labor directly due to high first cost of plant are of less relative importance than in European shops, where wages are lower.

IMPROVEMENTS IN SPECIAL MACHINES.

Generally speaking, the States have led in the production of specialized machines demanded by the manufacturer who produces large quantities, and who can afford to install a special machine for one particular operation. Machines of this type of a generally useful nature include:

Gear-tooth hobbing machines.
Gear-tooth milling machines.
Broaching machines.
Automatic chucking machines.
Multiple drilling machines.
Grinding—Internal cylindrical, external cylindrical, flat.
Turret machines of certain design.
Key seaters.
Cutting-off machines.
Gear-tooth grinding machines.
Worm-gear machines.
Thread milling machines.
Helical-gear-tooth machines.

Practically all of the above are now made by European machine tool manufacturers who turn out a first class article, in some cases superior to those made in the States. The types are all well known, and call for no special comment.

The most important advances recently made in particular types of machines meriting special attention are in:

1. Grinding machines.
2. Gear-cutting and tooth-finishing machines.
3. Auto-chucking machines.

Grinding Machines.

Although **External Cylindrical Grinding** with abrasive wheels has been done for many years, it is practically a new and a not fully developed art. Its successful use involves the correct combination of (1) the most suitable machine, (2) the most suitable grinding wheels, (3) the intelligent use of the trueing diamond. The leading wheel makers have a wide experience in selecting the most economical article adapted to give rapid and accurate finish. They are ready to make trials and tests to meet special demands of customers.

Machines especially for cylindrical grinding are well developed. The selection of abrasive wheels is largely empirical. The importance of the diamond for trueing the wheel is decidedly in the background. The modern shop, to derive the immense benefits of the grinding machine of today, can purchase good machinery from a number of well known makers. It must work closely with wheel makers to secure the right wheel for various classes of work. It must train men in the art of trueing and manipulating the wheel. There is not sufficient attention given to the training of expert grinding men who in the future will rank in importance with the turner, fitter and the tool maker.

The operation of cylindrical grinding is looked upon by most manufacturers as one to be adopted only where extreme accuracy is required. In reality the modern grinding machine combined with fast roughing lathe is one of the most economical machines known for producing ordinary cylindrical parts. The increased accuracy secured by finish-grinding, is in many cases as one might say "thrown in". It is believed that the savings which can be made in maintenance, repairs and running costs due directly to the accurate finish possible only on the grinding machine are scarcely realized. The recent experience of an important concern who adopted grinding as a finishing process is most suggestive. It is recorded that savings in repair to soft metal bearings amounting to $3,000 per month were made in one concern after the cylindrical bearings were finish-ground instead of being turned.

Internal Cylindrical Grinding is in its infancy. It has been forced upon us chiefly by the requirements of motor-car work

on hardened gears and cylinders. Its progress is confined on account of restrictions in size of grinding wheel. It does not seem to have been the subject of as much scientific study and tests as the external work. It is particularly lacking in that all-important feature to successful grinding, i. e., copious fluid supply. The development of good machinery of this type is limited to either the grinding out of comparatively small holes or of larger holes in light parts. Its usefulness can be much extended when makers bring out suitable machines for grinding holes in large, heavy, manganese parts. The manganese gear and bushing so far as tested show most remarkable wearing qualities (from 5 to 10 times that of ordinary steel) and resistance to shock. Its more extensive use is limited by the want of economically working internal grinding machinery.

Flat or Surface Grinding is still more or less a "tool room" operation. Recent developments however in the vertical spindle cup wheel grinder have shown good results where the abrasive wheel competes successfully with the milling cutter but not with such profitable returns as are secured through working the disk wheel grinder in combination with the roughing lathe. Undoubtedly the most striking results in flat grinding have been achieved with the very wide faced grinding wheel in the planer type machine, using a wheel 10 inches wide. In this machine the diamond trueing, as in cylindrical grinding, plays an important part. Wonderful accuracy has been attained as well as rapid production. It is not going too far into the realms of the imagination to conceive that much hand scraping may eventually be replaced by the flat grinding process.

Gear Tooth Grinding Machines.

In the machinery for finish-grinding the teeth of spur gears we find the most striking single example of a new mechanical operation that can be mentioned. Industrially it is most important. In the first place it is the only machine in which the last operation on the hard spur gear is done last, i. e., finishing the tooth. Secondly the peculiar process of tooth finishing in the machine referred to is accurate beyond any possibility of competition with any other known process. It overcomes one of the most troublesome details to master in the production of the motor-car as well as other mechanisms, that is, the produc-

tion of the accurate hardened gear. The machine referred to grinds from the teeth sufficient material to take out all hardening distortion, reducing the roughing out of teeth to a gashing operation with no accuracy beyond that of the most ordinary milling machine practice.

One other important feature in connection with this process should be mentioned. The engineer designer can now make use of accurate hardened spur gears, making use of material, speeds and tooth pressures which, without this process to assist him, it would be impossible to adopt. He can make extensive use of the manganese gear, the teeth of which can be accurately finish ground.

Gear Tooth Cutting Machines.

Modern gear tooth cutting machinery is distinguished by notable advances in accuracy of workmanship and speed of output. This statement applies to spur, worm and bevel machines. For the best spur gear work the automatic machine is now made with refinements to satisfy the most exacting, as far as machine work is concerned. In fact the limit of accuracy with the ordinary automatic gear tooth milling machine lies more in the exactness and manipulation of the cutter than in the machine itself.

In the hands of the ordinary machine shop operator probably the generating machine is the most satisfactory for the highest class work. For rapid production where accuracy is not essential there is a good variety of very efficient machines of the hobbing type. The bevel gear planer is now a highly perfected machine, giving all that is required in ordinary bevel gear production. The latest addition to this type is found in the new machine for producing spiral bevels. Machines are also well developed for producing accurate double helical gearing so much demanded.

There are also on the market various patterns of machines for the production of worms and worm gears. In these machines there are many new features which assist the manufacturer to turn out a product highly accurate and efficient. In no country has the refinement of the production of the worm and worm gears been so thoroughly developed as in Great Britain.

Generally speaking there is a constantly increasing demand for the accurate gear. There is not however a very wide realization of the fact that the quiet, efficient gear is nothing more nor less than the accurate gear.

Automatic Chucking Machine.

The automatic chucking machine, although it has been on the market several years, is comparatively an innovation. Where quantity production is concerned it is rapidly displacing the ordinary hand operated chucking lathes. It is (in Europe at least) being adopted in many cases by those who have previously had no organized "chucking" outfit or department.

It has the usual advantages of the automatic machine in saving labor costs. It is open to question if it has not been adopted in many places where labor is not expensive, with little or no saving in cost of production. Original purchase value and high machine upkeep charges are not always properly compared with the old costs on low priced simple outfits.

Cutting-off Grinding Machines.

Cutting-off grinding is a new process which should be mentioned. Remarkable results have been attained with a thin abrasive wheel used in a specially designed machine. In this machine alloyed metals which cannot be easily operated upon with ordinary tool steel can be rapidly cut.

DEVELOPMENTS IN PRACTICE.

In addition to improved details on standard types of machines, there have been most important developments in particular directions, such as:

1. Extended use of high speed steel.
2. Uses of alloyed metals and uses of the laboratory.
3. Application of limit gauge system.

High Speed Steel.

High speed steel is easily the leader in changes of a revolutionary character in machine shop practice. Its introduction forced machine tool makers to give consideration to designs principally in respect to

1. More rapid speed.
2. Faster feeds.

3. Greater strength and rigidity.
4. The liberal use of cutting fluids.

The publication of Fred Taylor's paper on the Art of Cutting Metals, as read before the American Society of Mechanical Engineers in December, 1906, was an epoch making event. The data recorded in the Taylor-White experiments is an invaluable guide to the design of modern machine tools. To the user it reveals the possibilities of rapid output, chiefly limited by the strength of the part to be machined in holding up to rapid feeds and speeds.

There is of course a large amount of light work on which the use of high speed steel is not an economy. On such work expense of the high speed cutting tool is hardly justified and the heavy high speed machine tool is not necessary. It will be found however that there is a large amount of light repetition work where high speed tools are warranted alone on account of the long time they will hold to size with comparatively little wear.

Purchasers of machinery will find it well to consider carefully if it is not profitable in many cases to pay the extra price asked for the many mechanical devices which distinguish the modern machine from the older type made only for carbon steel cutting tools. These devices include power movements, quick returns, gear box feeds, etc. Actual cutting times are so reduced by high speed steel that further economies in times of operations are only possible by the aid of the above mechanisms, combined of course with all time savings possible in the supply and removal of parts.

In view of the demonstrations and tests made by Taylor as to the value of the liberal use of cutting fluids in connection with high speed steels, it is astonishing how badly nearly all machine tools are designed to properly handle a large flow of cutting compound.

Taylor states in his paper that, "The average gain through the use of water on the tool for hard and soft forgings is about 40 per cent." Again, using "the best of modern high speed tool", there is a gain of 15 per cent in cutting a hard forging: a gain of 16 per cent in cutting cast iron. Yet in spite of these

statements makers continue to supply and purchasers continue to buy lathes, milling machines, drilling machines, grinders, turret machines and all sorts of machinery with, in most cases, no proper provision for dealing with cutting fluids, and in the majority of cases only apologies of devices for supplying a large stream of fluid. In many cases when pumps and pipes are supplied, evidently the machine shop floor is relied on as the final receptacle of the cutting liquid.

Use of Laboratory—Alloyed Metals.

Undoubtedly the modern shop is beginning to realize the value of the laboratory (1) as a guide in the selection of materials and (2) as an assistant in compiling practical specifications and inspection data.

Although there is hardly an article from a bedstead to a battleship in which an exact knowledge of material is not desirable, comparatively few manufacturers make use of the laboratory facilities now common.

Large concerns can support, with profit, their own scientific staff. Small concerns can make use of the numerous central laboratories which are well equipped and staffed, and which exist in nearly every engineering centre. The results of taking advantage of the scientific resources referred to, should be:

1. Selection of the best material for specified purposes.
2. The purchase of the cheapest material for this purpose.
3. The scientific inspection of material as it comes from the supplier so as to ensure a uniform quality.
4. A scientific and correct routine of heat treatment of material, hardening, annealing and tempering.

The motor-car industry alone has shown us possibilities in the use of alloyed metals that are of immense benefit to engineering generally, revealing to us a choice of metals in which we find the wonderful combination of light weight, great strength and high wearing qualities. One illustration of this is shown in the nickel-chrome steel as used for gear wheels in the transmission box of the ordinary motor-car. A comparison is made with ordinary case hardening steel.

Both after treatment	Ordinary case hardening steel	Nickel-Chrome Steel
Elastic limit in tons per square inch	20	105—110
Tensile strength in tons per square inch	30	120—125
Elongation in 2 inches	30	9—10
Contraction of area	60	25—30
Ball test (Brinell's)	131	477

The enormous difference in tensile strength in the above metals shows what a comparatively small section of nickel-chrome material can be used to carry a heavy load. The comparative hardness test is equally instructive. as showing possibilities in wearing qualities.

Another interesting example of the development in modern metallurgy is found in the manganese casting. Long tests for various purposes, as in rails and gearing, show that manganese has wearing and shock resisting qualities giving from 5 to 10 times the life of ordinary steel. There will undoubtedly be an increasingly extensive use of the manganese parts as soon as grinding machinery is made for finishing this material, which it is impossible to machine with the ordinary cutting tool.

The practical value of the scientific man to the engineer is admitted, but co-operation is not yet on a broad enough basis. It is too much restricted to the large industrial concerns. The modern machine shop, either large or small, can make profitable use of laboratories in chemical analysis, physical tests, and accurate heat treatment routine to replace the old rule of thumb.

The Limit Gauge System.

The so-called limit gauge system is as old as the manufacture of interchangeable work. It is extensively used in certain industries which cannot do without it. It is used by many who have little understanding of its value and correct application. It is neglected entirely by the majority of manufacturers.

Broadly speaking, it is the use of a tool (the limit gauge or any other gauge) by which the workman produces parts with clearances determined by the engineer and not left to judgment of the individual worker. Its practical field is limited on one side by extremely fine fits, on the other, by very loose fits. The so-called "limit" gauge is not the only gauge for all classes of work. It is often best made use of in conjunction with the

micrometer. The gun and rifle maker, the manufacturer of sewing machines, typewriters, etc., needs no instruction in its application. It is in the general engineering work where it is either wrongly or foolishly adopted, or not in use at all, even when it is of much practical value.

It is not necessarily connected with production in large quantities only. Its principles may be adopted in the production of one piece. In this no "limit" gauge may be used but limits of accuracy may be fixed in the drawing office. Possibly the gauging may be done by ordinary spring calipers.

The adoption of the limit gauge system in any shop should be preceded by careful accurate measurements of parts which are known to be of the right dimensions. These dimensions should then be tabulated and classified. After this, an intelligent study should be made of the forms of gauges or measuring instruments to be adopted. How far the system can be applied, with profit and good results, should be determined by actual use.

The working application should not be undertaken too extensively at first. A gauging system, like a card system, depends for its intelligent and profitable use on the correct habits of those who use it. These habits cannot be acquired except by careful methodical training of staff and operators. Start with a certain few sizes of standard clearances, get them well working in drawing office, shops and inspection department, and gradually build into and extend them.

If this method of introduction is followed, results will be most quickly attained with a minimum expenditure for outfit, and limit gauges will not be condemned as an extravagant and useless fad.

In addition to machinery and tools, should be mentioned those details of general shop equipment as lighting, heating and ventilating, shop fittings and furniture, etc., all of which receive much more attention than formerly. These details which conduce to order, cleanliness and comfort are no longer looked upon as luxuries, but economies. Nearly every item of this class of equipment has been the subject of detailed study on the part of the specialist in much the same manner as the machine tool.

SHOP ORGANIZATION AND MANAGEMENT.

A review of shop methods is not complete if no reference is made to those essentials of organization without which successful administration is impossible. Gilbreth classifies present-day shop management as follows:

1. Traditional.
2. Transitory.
3. Scientific.

These terms are comprehensive. They can be well applied in the self-examination to which every manager should submit himself. In this examination he is sure to find in one form or another some or all of the elements of organization given below, usually in the Traditional, or the Transitory, rarely in the Scientific stage.

There are three broad divisions of management:

1. Technical.
2. Commercial.
3. Production.

It must suffice to merely give some of the main items under each of these divisions, which must receive attention in every shop, large or small.

Technical.

1. Design.
2. Experiment and Testing.

Commercial.

1. General Management.
2. Purchasing.
3. Estimating.
4. Sales.
5. Valuation and Depreciation.
6. Statistical Returns.
7. General Accounting.

Production.

1. Standardization.
2. General organization of plant.
3. Designs of special plant, tools, fixtures, etc.
4. Tool room.
5. Power plant and maintenance.
6. Inspecting.
7. Stores organization.
8. General costing.
9. Rate fixing.
10. Time studies.
11. Progress department.
12. Works accounting.
13. Welfare and apprentice systems.

The special object of this paper is to discuss details of modern mechanical equipment and processes. The successful (i. e., profitable) use of the best mechanical outfit is, however, so dependent on good management that it is thought best to briefly touch upon the development which has taken place in relation to so-called "scientific management."

We can point to many examples of elaborately equipped factories working with little or no profit, to many badly equipped factories making money. Instances of well equipped works operated under scientific management and in complete harmony with the sales department, and paying dividends, are not so common. Undoubtedly this latter is the ideal money making establishment. A scientifically managed plant is nothing more nor less than one in which maximum output is secured at the lowest cost. The elements of such a management are known and tabulated. Their practical working is demonstrated. A complete working establishment is a rarity. Not one is known in Europe. A machine can be bought, paid for, delivered, set up and made to turn out work. Scientific management cannot be passed over the counter for a fixed price. It requires talent, backing and co-operation to ensure its successful working. It is understood least of all by those who are in leading positions in our industrial concerns, on whom original initiative falls.

Generally speaking, mechanical outfit proportionally receives too much attention as a means of increasing efficiency. In nine factories out of ten, costs can be reduced and output increased by scientifically operating existing plant with much more profitable returns than are possible by installing new machinery. It is not putting it too strongly to state that it is practically impossible, in any other manner than that pointed out—by scientific management—to reap the full benefit of high speed steel and of our highly developed mechanical outfit. The inventor is not as much wanted as the organizer. It is quite easy to purchase with other people's money new machines. It is hard, slogging, uphill work to install an up-to-date system of efficient management. To those who attempt it no better words can be quoted than the following from Hamilton Church: "Few people understand that the principal work of an expert organizer is not the designing of elaborate blanks and cards, but

the fostering with tireless patience of correctly adjusted habits in each member of the staff.''

In respect to commercial management and sales work the ''modern'' shop makes exacting demands. In limited companies especially, the ''policy'' or lack of policy of the Board of Directors is often a perpetual handicap to profit making. Again the sales department may, by continually disregarding engineering difficulties, saddle works with execution of unsuitable orders, preventing the realization of profits and make it impossible to perfect methods of production and refinements of design. The more energetic the salesman is in this case the more harm he does to the business.

The thoroughly ''modern'' shop is one in which we find the best mechanical equipment operated under scientific management, controlled by a commercial policy fully appreciating engineering requirements.

DISCUSSION

Mr. Hartness. **Mr. James Hartness,*** Mem. Am. Soc. M. E., in opening the discussion stated that there was no man on earth better qualified than Mr. Orcutt to review machine-shop practice. He was an American in a way, was acquainted with German practice and lately had been an Englishman.

In commenting on the statement of Mr. Orcutt that, ''There are not enough of the old type of American mechanics in the States to meet demands'', he said that men of thorough mechanical training were scarce and that there was in consequence a great opportunity for young men in this field.

These young men must always know that we are dealing with human beings as well as machines. We must realize that every man has a heart. Unless we bear this in mind, we fall short of carrying out the ideas Mr. Orcutt has so well set forth.

Mr. Barth. **Mr. Carl G. Barth,**† Mem. Am. Soc. M. E., expressed agreement with Mr. Hartness. He thought the best way of treating the man in the shop was to make the equipment the very best possible. By taking care of the machinery you would be treating the men kindly, which was what he did.

Mr. Langille. **Mr. H. B. Langille**‡ asked for information as to results in the use of ball and roller bearings in machine tools.

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* Pres., Jones & Lamson Mch. Co., Springfield, Vt.

† Cons. Eng., Philadelphia, Pa.

‡ Instr., College of Mechanics, University of California, Berkeley, Calif.

Mr. Carl G. Barth stated that sixteen years ago, while with the Bethlehem Steel Co., they had trouble with a Pratt and Whitney boring machine. They had been asked if they wanted ball bearings in the mill, but having been brought up with Mr. F. W. Taylor, who had influenced him against them, he had said ''no''. Since then he had changed his mind, and had been the first to put ball bearings as thrust bearings in a drill press. During late years, he had placed ball and roller bearings in a great deal of machinery, and had never had any trouble with them. He thought they were the coming thing and that we would have very inefficient machinery without them. Mr. Barth.

Mr. Hartness said that perhaps due to ignorance on his part in the matter of design, he had found difficulty in putting ball bearings in lathe spindles. They had chatter trouble and the ball bearings seemed to increase it. While it seemed unfair to ball bearing people to charge it to ball bearings, it was his experience. Mr. Hartness.

He thought that thrust bearings could be made of ball bearings to advantage in lathes and drill presses. They were very important in small gearing and should be used on transmission shafts.

Paper No. 119

MACHINE SHOP EQUIPMENT, METHODS AND PROCESSES.

By

E. R. NORRIS, Mem. Am. Soc. M. E.
Dir. of Mfg. Operations, Westinghouse Electric & Mfg. Co.
East Pittsburgh, Pa., U. S. A.

Many important developments in machine shop equipment and practice have occurred recently, and while it is possible to collect and review only a few of these in the space allotted to this article, the few examples presented may be considered as fairly representative of the progress, and may, in a measure, indicate present trend of development.

It is about fourteen years since Messrs. Taylor and White discovered the special treatment which gave to the world high-speed steel, and while it was early predicted that the use of this steel would revolutionize machine tool equipment and methods of manufacture, it naturally took some time for machine tool builders and users to fully realize the changes which had to be made in equipment and methods, in order that the demands of the new steel might be met in an efficient manner. The greatly increased feeds, speeds and depths of cut, which were possible by the use of the new steel, made it necessary for the builders of machine tools to redesign their tools along heavier lines, with greater pulling power, and later to equip the machines with quick changing and automatic or semi-automatic attachments to facilitate the handling between cuts.

The large manufacturer had to be particularly careful in adopting high-speed steel when it was first introduced, his equipment not being suitable for its economical use; also, having a large stock of carbon and mushet steel tools, it was reasoned, and rightly so, that the change to high-speed steel must be made gradually. The new steels also made it possible for the

machine operators to increase their productive capacity without an equivalent effort on their part, and it naturally followed that time and money values on work had to be adjusted to meet the new condition. Shops working under the premium plan of payment, or similar systems having a sliding scale of pay depending on the time taken to perform work, were in a position to adopt the new steel in many cases before values were adjusted to meet the new conditions. Under piece work or similar systems of payment, however, it was absolutely necessary to promptly adjust the price paid, in line with the savings in time made with the new steel, and there is no doubt that this fact, in a great many cases, retarded considerably the general adoption of the steel. During the period between 1898 and 1900, Messrs. Taylor and White discovered and developed the process of treating tools made from chromium-tungsten steels; and while shortly after this time it was generally known that steel of this kind heated nearly to the melting point would do considerably more work, comparatively few took full advantage of the steel until Mr. Taylor's paper "On the Art of Cutting Metals" was published in 1906. This paper created a profound and world wide interest in steel; and while the paper dealt only with the results obtained with forged cutting-edged tools of lathe and planer types, its value was well known, and the new steel was rapidly substituted for the steels which were being used for drills, milling-machine cutters and other kinds of cutting-edged tools.

Before entering into a detailed discussion of these matters, it may be well to state that for convenience the subject matter has been arranged in four groups, which will be taken in the following order:

Special alloy steels and Stellite
Machining with edge tools
Grinding
Electric driving for machine tools

Special alloy steels: their composition, treatment, application and effect on machine shop practice.

Shortly after the publication of the paper "On the Art of Cutting Metals", many steel manufacturers became highly interested in the subject, and, as a result, many varieties of the tungsten-chromium steels were rapidly placed upon the market

by both home and foreign producers. The so-called "air hardening" steel, introduced by Robert Mushet about the year 1870, contained the essential elements of a high-speed tool steel, and required only the special treatment discovered by Messrs. Taylor and White to improve the high speed cutting qualities. Considerable development was necessary, however, before the high cutting speeds and durability, which are common today, were rendered possible. The annexed table indicates some of the changes which have been made in the chemical composition of high-speed steel up to the present date:

	Tungsten	Chromium	Carbon	Manganese	Silicon	Phosphorus	Sulphur	Molybdenum	Vanadium	Cobalt	Nickel	Copper
Mushet (Air Hardening)	5.441	0.398	2.150	1.578	1.044							
Midvale (Date 1895).........	7.723	1.830	1.143	0.180	0.246	0.023	0.008					
Recent Make.........	16.28	4.26	0.63	0.10	0.141	0.008	0.018	0.55	0.26	3.47	*Tr	*Tr

While this research and development finally benefited the user, he was at first involved in considerable expense in efforts to select, from the many brands available, the best steels to use for different purposes. The following investigation is typical of the tests which were carried out by users at about that time.

Twenty different brands of tool steel—ranging in price from \$0.38 to \$1.00 per pound (\$0.84 to \$2.205 per kilogram)—were selected and tested in order to determine which kinds would be the most efficient for the work in hand. From each brand of steel, tools were forged, hardened and ground under the direction of a specialist. The heat treatment was carried out in accordance with the steel manufacturer's instructions, and standard cutting angles and shapes were closely adhered to. The tools were first tested on axle-steel shafts, containing approximately 0.45 per cent carbon, at a cutting speed of 103 feet (or 31.39 meters) per minute, the feed being 1/40 of an inch (0.634 mm) and the average depth of cut 5/32 of an inch (3.97

* Tr indicates trace.

mm). A stream of cutting compound was directed on the tool. It is interesting to note the wide variation in the amount of work done by the different kinds of steel. Fig. 1 shows that the tool giving the best performance removed 570 cubic inches (9336 cu. cm) of metal for each grinding, whereas the tool at the bottom of the list removed only 38 cubic inches (622 cubic cm) of metal per grinding. Three tools were made from each kind of steel, and the best result from each set of tools was recorded in the chart.

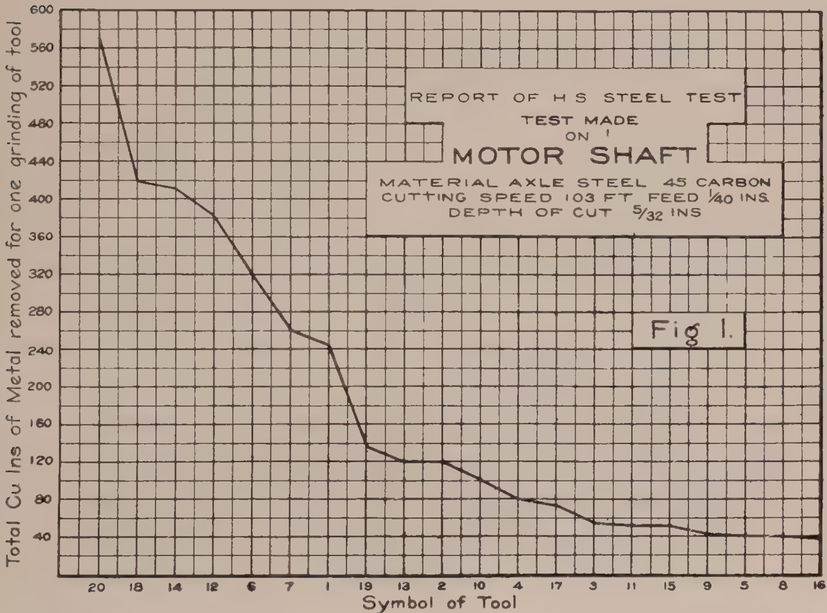

Fig 1.

(NORRIS)

A second test was made on malleable cast iron spiders, which, having four ribs each, provided an intermittent or broken cut, thus giving the tools a more severe test than would have occurred had the cut been continuous. A cutting speed of 55 feet per minute (16.73 metres per minute) was used on the first four spiders; this was increased to 60 feet (18.29 metres) per minute on the next four spiders, and a speed of 65 feet per minute (19.81 metres per minute) was maintained on all subsequent

spiders until the tool was ready for regrinding. In all cases, 1/12-inch (2.12 mm) feed was used, and the average depth of cut was 7/32-inch (5.56 mm). Fig. 2 shows the amount of metal removed for each grinding of the various tools; the symbols shown on the curves were for purposes of identification of the steels used.

Superior grades of high-speed steel, though of high efficiency from a cutting standpoint, are often rejected on account

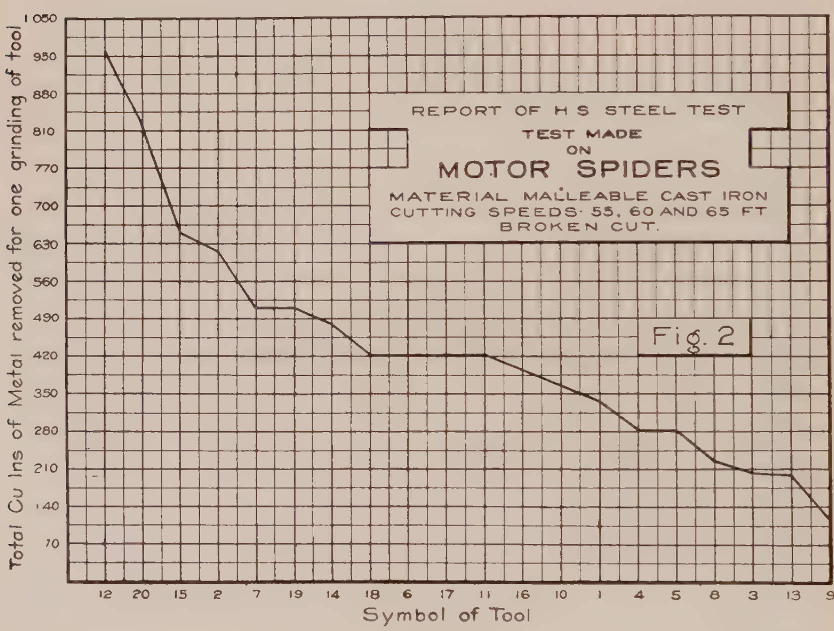

Fig. 2

(NORRIS)

of the high cost of the investment. Tool holders reduce this investment to some extent, however, but their use is somewhat limited, owing to the fact that in many places a solid tool can be manipulated to greater advantage.

From time to time, various tests have been made on butt-welded tools and on tools formed by welding tips of high-speed steel to low grade carbon steel shanks. The electrical welding process as applied to work of this kind is quite successful. A very important consideration, however, is the one of relative

cost of solid and welded tools. To illustrate this point, consider a ¾-in. by 1½-in. (19.04 by 38.1 mm) round-nosed lathe tool made, first, as a solid high-speed tool; secondly, from low grade carbon steel shank with two inches of high-speed steel butt-welded on same; thirdly, from carbon steel shank with small high-speed steel tip, welded on. Reference to the annexed table will show the first costs of solid, butt-welded and welded-tip tools to be $2.74, $1.08 and $0.80 respectively, the figures being based on high-speed steel at $0.60 per pound ($1.32 per kilogram).

Solid Tool—¾ by 1½ by 12 in. Long. (19.05 by 38.1 by 304.8 mm)

Cost of first tool	$2.74
Six additional reforgings and hardenings	1.20
69 additional grindings	5.17
Total cost during life of tool	9.11
Salvage	1.07
Net cost	$8.04

Butt-Welded Tool—¾ by 1½ by 8½ in. Carbon Steel (19.05 by 38.1 by 216 mm) 3 Pcs. ¾ by 1½ by 2 in. (19.05 by 38.1 by 50.8 mm) H. S. S.

Cost of first tool	$1.08
Two additional pcs. of high-speed steel	.80
Preparing for and welding (2 welds)	.46
Six additional reforgings and hardenings	1.20
69 additional grindings	5.17
Total cost during life of tool	8.71
Salvage	.04
Net cost	$8.67

Welded-Tip Tool.

Cost of first tool	$ .80
Six high-speed steel tips	2.04
Preparing for and welding (6 welds)	1.20
69 additional grindings	5.17
Total cost during life of tool	9.21
Salvage	.04
Net cost	$9.17

Thus the initial outlay for the solid tool is considerably greater than that for the welded-tip tool. The cost of up-keep must be considered, however, and further reference to the table,

which is based on 70 grindings as being the life of each tool, shows that the final costs of the solid tool, the butt-welded tool and the welded-tip tools are $8.04, $8.67 and $9.17 respectively. It may appear, at first sight, that the allowance for salvage on the solid tool is high, but when it is considered that scrap ends are forged down and used for smaller tools or the teeth of milling cutters, it will be seen that the depreciation is very small.

The substitution of high-speed steel for carbon steel and mushet steel naturally took place first in those cases where tools were comparatively simple in construction—as in lathe and planer tools—and while the increased output, due to greater cutting speeds and feeds, was truly remarkable, there was a still more remarkable increase in the output from the drills and milling machines, after these latter had been equipped with the new steel tools. This, no doubt, was due in a measure to the fact that in the case of the lathe and planer, the transition was frequently made from mushet steel, with its cutting speed of approximately 30 feet (9.14 metres) per minute to high-speed steel of perhaps 60 feet (18.28 metres) per minute cutting speed; whereas, in the case of the drill and the miller, the change was made, in the majority of cases, from slow-speed steel tools directly to the new high-speed steel tools.

High-speed steels are now commonly used in modern machine shops for turning, boring, planing, shaping, milling, drilling and punching, the most noteworthy exceptions to this rule being found in shops where the product consists chiefly of articles made from the softer metals or their alloys, in which cases the carbon steels are often preferred. There are many purposes, however, for which carbon steel tools are used and will continue to be used in all shops. High-speed steels are also being used with success in the manufacture of slotting dies. There are at least two reasons why the use of high-speed steel for this purpose has been somewhat delayed, the first being that the speed of a punch or shear press is usually determined by the speed at which work can be fed; the second being due to the risk in hardening expensive dies. The following record of tests made with dies of carbon steel and high-speed steel is interesting.

The work selected was the punching of notches in sheet steel of 0.0172 inch (0.436 mm) thickness. This was done on an

automatic notching machine which runs at the rate of 300 notches per minute—the maximum speed at which the work could be indexed with accuracy. Carbon and high-speed steels were run at the same speeds, and it was found that carbon steel dies required grinding oftener than the high-speed steel dies in the ratio of 2.4 to 1. The curves given in Fig. 3 show the number of notches punched for each grinding of the die. It can be seen that at the end of the tenth grinding the die made from the

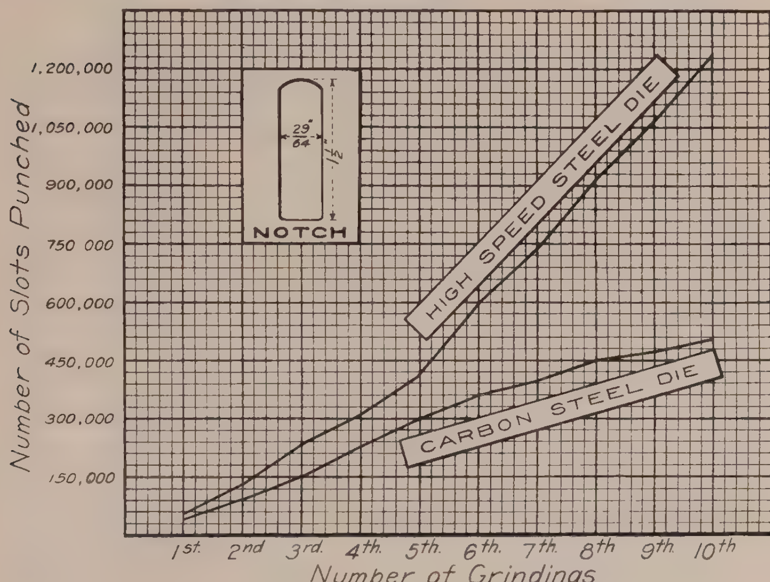

Fig. 3. (NORRIS)

high-speed steel had punched 1,239,000 notches, whereas the carbon steel die had punched 506,000 notches.

The use of high-speed steel dies increases the production somewhat, as they do not require grinding so often as carbon steel dies. The greatest saving, however, is to be found in the cost of the dies themselves. From data collected from tests similar to the above, it has been found that the relative costs of carbon steel dies and high-speed steel dies, for a given production, are approximately as two is to one. The loss due to hardening is very small, being slightly under one per cent.

HEAT TREATMENT OF TOOLS.

The heat treatment of the new steels has remained fundamentally the same since they were introduced. Modifications have been made in the apparatus used for the heat treatment of tools. Electrically heated oil baths provide a handy means of drawing the temper. Lead baths are also used, with thermocouples and galvanometer for temperature control. The galvanometer has several contacts—one for each thermo-couple and one for the off position. The accuracy of each electric pyrometer is checked occasionally with a standard instrument, which is kept for that purpose. Heat treatment records are conveniently kept in a card index.

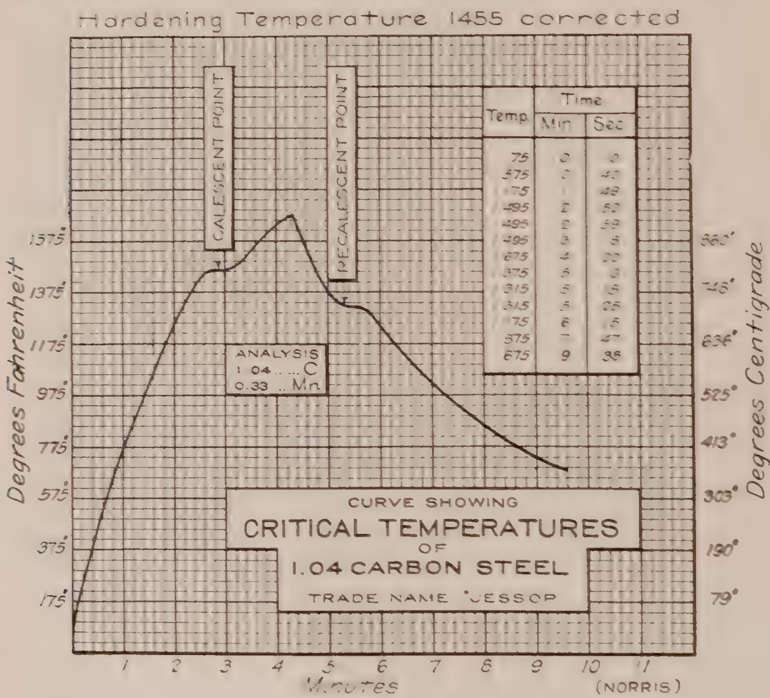

Fig. 4.

When a new brand of steel is introduced, the determination of its critical temperature is usually necessary. This is conveniently carried out by means of a small electric furnace.

in conjunction with a thermo-couple and galvanometer. Small pieces of steel under test are clamped to the side of the thermo-couple and inserted in the furnace. The temperature of the furnace is raised slowly, and simultaneous readings of time and temperature are taken, from which the critical temperature curve of the steel is plotted. Fig. 4 shows such a curve which was taken from a piece of 1.04 per cent carbon steel.

STELLITE.

A substance placed upon the market under the name of Stellite is claiming considerable attention as a high-speed cutting material. Stellite is not a steel. A recent analysis of a sample gave the following chemical composition:

Cobalt	Chromium	Tungsten	Iron	Nickel	Manganese	Silicon	Molybdenum
52.03	29.36	12.71	5.35	0.45	0.24	0.09	Trace

Stellite cannot be forged, rolled or machined, is extremely brittle and tools made from it must be well supported close to their cutting edges. It is supplied by the makers in short cast bars of such sections as may be ground to form tools of simple outline and construction; hence its uses are at present somewhat limited.

Stellite tips may be brazed or electrically welded to shanks of carbon steel, and when so treated, may be used until repeated grindings render the stellite very thin. Fig. 5 shows two turning tools which were formed by welding stellite tips to carbon steel. These tools continued to cut well until their tips were reduced in thickness, by repeated grindings, to the condition shown. The photograph also shows two tool holders which support their tools close up to the cutting edges and are, therefore, especially suitable for stellite.

Under favorable circumstances, cutting speeds may be greatly increased by the substitution of stellite for high-speed steel. Many cases are on record where cutting speeds on machinery steel have been quadrupled. The following instances may be of interest. Thin cast iron frames, which were very hard on account of their being somewhat chilled, were successfully faced at a cutting speed of 300 feet (91.44 metres) per minute by the use of stellite, whereas the speed for high-speed steel was 45

feet (13.72 metres) per minute. In this case, there was also a decided reduction in the time spent on grinding tools, the stellite tool finishing nine pieces for each grinding as against one piece finished for each grinding of the high-speed steel tool. On an axle-steel shaft of 0.45 carbon, the cutting speed was increased from 100 feet (30.48 metres) per minute to 305 feet (93 metres) per minute, when stellite was substituted for the usual high-speed tool. Sandy brass castings have also been machined with considerable success by the use of stellite tools—the cutting speeds being doubled. At present, stellite does not give

Fig. 5. Stellite-tipped Tools and Tool Holders.

good results where the cutting is irregular or broken, but where a continuous cut of uniform depth, with small feed, can be used, it will frequently be found that a high rate of cutting, together with a uniform size may be maintained.

MACHINING WITH EDGE TOOLS.

Machine tool manufacturers have shown considerable enterprise during late years in dealing with the problems and possibilities presented by the introduction of the new steels. Since greater cutting speeds, feeds and cuts were possible, it became at once apparent that machine tools of greater strength and rigidity, combined with closer speed regulation, were highly desirable. Also, since the cutting speed had been increased, the handling time became of greater relative importance; consequently, machine tools have been produced in which the leading features and improvements are rigid construction, large wearing

surfaces, improved means of lubrication, superior balance—both in the parts of the machine and in the tool reactions—an increased number of available cutting speeds and feeds, closely graduated indexes, enhanced facilities for simultaneous operation and automatic and semi-automatic time-saving devices. Thus, the selection of the most suitable machine for a specific manufacturing operation has become a matter which requires considerable skill and experience.

The selection of machinery for machine shop purposes must depend not only upon the design, size, accuracy and finish required by each class of work, but also upon the quantities which may be manufactured and carried in stock at one time. The following practice, which calls for the use of parting-off machines, centering machines, special rough-turning and spotting lathes, cylindric grinding machines and milling machines has been found satisfactory for the manufacture of accurately finished steel shafts, which range in size from 1½ in. dia. (38.1 mm) by 15 inches (381 mm) long to 4½ in. dia. (114.3 mm) by 5½ feet (1.68 metres) long and are manufactured in quantity.

The material from which the shafts are made is hot-rolled axle steel, which has been carefully selected under rigid inspection at the mills. It contains about 0.44 per cent carbon and 0.55 per cent of manganese. The ultimate tensile strength must not be greater than 90,000 pounds per square inch (6328 kg per sq. cm) or less than 75,000 pounds per square inch (5273 kg per sq. cm), and the elongation in 2 in. (50.8 mm) must not be less than 18 per cent. The material is in about 22-foot (6.7 metres) lengths, when received from the mills, and is cut to the desired lengths after arrival at the works, these lengths being usually 1/32 inch (0.79 mm) to 1/16 (1.59 mm) longer than the finished lengths of the shafts. Several kinds of machines are used for cutting this material to lengths. The hollow-spindle cutting-off machine, with its forged steel tools, has been largely abandoned in favor of the revolving-cutter type of cutting-off machine. In the external revolving-cutter type, high-speed steel cutters, which are adjustable, are inserted in the rim of the revolving disk. The machine is provided with a very handy pneumatic clamping device by means of which the work is rigidly and rapidly fixed in position. In another machine, the cutters are

arranged around an inner circumference of an annular disk. This machine is built to take stock up to 6 inches (152.4 mm) in diameter, and the cutting is done by eight inserted high-speed steel cutters. Four of these cutters are round-nosed for roughing and four are square-nosed for finishing, so arranged that each square tool follows a round-nosed tool. The machine is driven by a constant speed motor of 710 revolutions per minute, which gives a cutting speed of 47.6 feet (14.5 metres) per minute. The length of bar stock is conveniently adjusted by means of hand wheel, rack and gearing, one of the round ways upon which the carriage slides being graduated in feet and inches. A pneumatic clamping device, similar to the one used with the external machine, is also used with this machine. As these machines are used on rectangular and round bars, both external and internal designs are desirable, the latter being more suitable for round stock. Some idea of the relative values of the hollow-spindle cutting-off machine and the internal cutting-off machine may be obtained from the following figures, which were obtained by tests made on an axle-steel stock 4.75 inches (120.65 mm) diameter by 22.5 feet (6.86 metres) long.

	6 in. (152.4 mm) Hollow-Spindle Cutting-Off Machines	6 in. (152.4 mm) Int. Cutting-Off Machines
Cutting speed........	64.5 ft. (19.66 metres) per min.	47.6 ft. (14.5 metres) per min.
Feed per min.	0.25 in. (6.35 mm) per min.	2.0 in. (50.8 mm) per min.
Total time on six cuts..............	1 hr., 16 min., 10 sec.	33 min.

Centering. After the shafts have been cut to length they are next centered in a double-head centering machine, which has two self-centering chucks. By this machine, true alignment of centers is secured, and as only one setting is required for centering both ends, this method is quicker than the older method in which a single head was used. Due to rough turning operations, the centers are subject to very heavy stresses, and where the centers are not in alignment these stresses are greatly increased, the centers wear rapidly and the shaft does not run true. This renders necessary an increased allowance of metal for grinding. The centers are drilled with a combina-

tion center drill, which drills the pilot hole, counter sinks to 60 degrees and also counter bores the shaft to a depth of $\frac{1}{16}$ inch (1.59 mm). As all shafts on one order must have their centers of uniform depth, so that length stops may be used on the lathe, the center drill is provided with a stop.

Rough-turning Shafts for Grinding. The third operation on shafts is that of rough turning and spotting. Shafts from 1½ inches (38.1 mm) dia. by 15 inches (381 mm) long up to 4½ inches (114.3 mm) diameter by 5½ feet (1.68 metres) long may be conveniently rough turned, spotted and threaded in a special lathe. This lathe is equipped with adjustable stops for length and cross feeds, which, after the first setting, render calipering unnecessary and insure uniformity in the spotting for grinding. There are three tools, one for roughing, one for spotting and one for rough cutting the thread. Four cuts are taken with the threading tool, after which an adjustable die head, arranged over the tail-stock spindle and lathe center, cuts the threads to within (0.254 mm) 0.010 inches of the finished size. The thread is brought to size by means of a hand die after all the chief operations have been performed on the shaft; this insures a true thread and corrects any abuse which the thread may have received in handling, while going through the various operations.

Milling Keyways. The next operation is that of milling the keyways. These are milled on a heavy vertical milling machine built for work of this class and provided with a two-fluted end-mill cutter. The cutter or end-mill is held in the spindle of the machine by a draw in collet, run at a high speed and flooded with cutting compound. The shaft is located in the machine by a self-centering device and an end stop. The keyway is then cut by feeding the cutter down to a depth stop by hand, after which the longitudinal feed is used and automatically thrown out by a stop which is set to suit the length of the keyway.

If the ends of keyways are not required to fit round-ended keys, it is found economical to place a number of shafts on "V" blocks and mill them by means of gang milling cutters, which are carefully spaced on the arbor. Where keyways have been cut by this latter method and the design calls for round-

ended keys, it is necessary to transfer the shafts to an end-milling machine; and experience shows that it is more economical to complete the operation on one shaft at a time on a vertical machine, because the extra handling and time taken to re-set the work for end milling more than offset the gain made by milling several keyways simultaneously.

Grinding. The final machining operation on the shafts is that of grinding. Satisfactory grinding results can only be obtained by the use of rigid and accurately aligned grinding machines, in which the work is well supported by centers and steady rests, and where due attention has been paid to the grade of wheel, its diameter, width, peripheral speed and also speed and traverse of the work. Careful attention must also be given to the truing of the wheel, if a true and high finish is desired. The method of handling and grinding shafts depends somewhat on their size and the quantities manufactured at one time. On all heavy shafts it is the practice to rough and finish-grind complete the entire shaft before removing it from the grinding machine, except in those cases where the shaft has a taper, in which case the shaft is transferred to another machine to receive the taper grinding operation. In the grinding of heavy shafts, the fits are first ground to size and the journals, or bearings, are rough-ground to approximately .003 inches (.076 mm) larger than the finished size, the wheel is next trued up and the bearings finished. In dealing with shafts which may be easily handled by hand, the better practice is to rough-grind journals, grind the fits to size and remove shafts from the machine. After about 50 shafts have been so treated, the wheel is carefully trued up, the shafts replaced in the machine and the journals finish-ground to size.

MILLING.

Great advances are being made in milling practice as a result of recent experiments with "stream lubrication". These experiments have shown that cutter and work can be kept cool under very high speeds and feeds by the application of a sufficient quantity of cutting compound. The compound is conveniently and effectively applied to the cutter and work by means of a hood.

Some idea of the importance of "stream lubrication" may be gathered from the following data, which have been taken from various tests. By using stream lubrication while cutting the teeth of a long pinion, it was possible to increase the speed 71 per cent and to increase the feed 164 per cent. The speed at which keyways in chrome-nickel steel shafts were milled was increased 36 per cent and the feed 90 per cent. By the same means, the speed for milling the teeth of machinery steel sprockets was increased 86 per cent and the feed 50 per cent.

Stream lubrication is being used to advantage in cases where, owing to limited capacity of the machine, speeds and feeds cannot be increased. The following is an instance of such a case. In milling grooves to form bars of "H"-shaped section, it was possible to mill 300 pieces for each grinding of the cutter—stream lubrication being used—whereas, with the ordinary lubrication, the cutter had to be ground after 15 or 20 pieces.

While stream lubrication gives excellent results on steel of various kinds, it is not always satisfactory when used on cast iron. This appears to be the case where the hard skin of cast iron must be encountered at all parts of the traverse, as for instance where the cutter is wider than the surface of the casting, and the vertical edges of the casting skin are presented to the cutter at two places only, which are separated by a distance equal to the width of the casting.

Since the cutting speeds and feeds have been greatly increased, it is evident that the ratio which the handling time bears to the total time of any milling operation will be greatly increased, unless improved handling and chucking facilities commensurate with the increased cutting capacity be installed. It is also evident that the highest efficiency can be obtained from operator and machine, only when the cutting proceeds continuously. This condition may be obtained, approximately, by what has been called the "continuous" method of operation. The "continuous" method may be used where the work is of such a size and shape that a circular milling attachment or a machine having two or more revolving tables can be used. Continuous milling is employed in finishing the base plates of electric sad irons by mounting them on a circular milling at-

tachment. This circular attachment is provided with 10 independent chucks for holding the castings, thus allowing the operator time to take out the machined castings and put in other castings while the cut proceeds. The efficiency, in this example, may be gauged by the fact that the work was formerly done by one operator on two vertical milling machines fitted with transverse feed, magnetic chuck and high-speed cutters. The output was doubled and 50 per cent of the floor space saved by the new method.

Brass cable terminals are also milled continuously.

In a comparatively recent machine for continuous milling, two tables, which carry the work, revolve about a central column, the revolving and indexing being actuated by means of a foot lever. The operations of this machine are so arranged that the time for setting up the work is equal to or less than the time required to make the cut. Under these circumstances. the only lost time between cuts is 10 seconds, the time required to revolve and index the tables—to which must be added, where the work is short, the time required to traverse the work to and from the cutter at the beginning and end of each cut. As an instance of the saving effected by this machine, may be cited a case where steel keys 9 inches by $1\frac{1}{4}$ inches wide (288.6 by 31.75 mm), set up two at a time on each table, were milled on both faces in an average time of 3.45 minutes each; whereas the time required to do this work on an ordinary milling machine was 7 minutes each. By mounting 6 pieces on each table, the time per piece was reduced from 3.45 to 1.5 minutes each.

The uses of the spline miller have been extended, so as to include curved slots and forms in endless variety, by an ingenious and inexpensive camming attachment. The attachment consists of an angle bracket which is bolted to the platen and carries a supporting roller for the cam. A face plate, or carriage, to which the work is attached slides on the angle bracket, being actuated by a small roller as it travels upon the upper edge of the cam. The pressure between roller and cam is regulated by a spring. One end of the cam is fixed by a tap-bolt to the frame of the machine, the other end being supported by a roller. Straight slots may be produced by fixing the face plate to the angle bracket by means of a wing-nut

and stud. This camming attachment has been found remarkably efficient for rounding off the ends of pinion teeth.

As an example of heavy milling, Fig. 6 shows the milling of axle-cap seats in a large steel railway motor frame. It will be noticed that six surfaces are being milled simultaneously. High-speed steel, inserted cutters are used, the cutting speed being 67 feet (20.4 metres) per minute, the feed per minute $1\frac{15}{16}$ inches (49.2 mm) and the depth of cut ½ inch (12.7 mm).

DRILLS AND DRILLING MACHINERY.

Although the first cost of high-speed drills is much more than that of carbon-steel drills, high-speed steel is now in general use for all drills above $\frac{3}{16}$ inch (4.76 mm) diameter; and while carbon steels are frequently preferred for the smaller sizes where the material to be drilled is chiefly brass or cast iron, it will be found economical to use high-speed drills for the small sizes where much steel has to be drilled. There are several reasons why high-speed drills are so generally used, the first of which is undoubtedly their great cutting capacity. Carbon-steel drills are commonly used on machinery steel, with 0.005 to 0.01 inches (0.127 to 0.254 mm) feed per revolution, at a peripheral speed of 20 feet (6.09 metres) per minute, while high-speed drills are ordinarily driven at a peripheral speed of 70 feet (21.33 metres) per minute, with feeds ranging from 0.010 to 0.015 inches (0.254 to 0.381 mm) per revolution; and cases are on record where, under best conditions, high-speed drills have been used successfully at a peripheral speed of 135 feet (41 metres) per minute, with a feed of 0.06 inches (1.52 mm) per revolution. Another reason why high-speed drills are preferable is found in the saving of grinding time. Still another reason appears in the reduction of the number of drills carried in stock, for, owing to the frequent grindings necessary with carbon-steel drills, operators frequently carried three or four drills of the same size, so as to save the time which would otherwise be lost in walking to and from the emery wheel.

As in other machine tools, the adoption of high-speed steel for cutting has been followed by the re-design of the machines, due regard being paid to the element of rigidity and the power

required to drive the new drills to the limits of their capacity. Belt-driven feeds have been largely superseded by spur-geared feeds, and cast iron gears have given place to cut steel and bronze gears. All important bearings are bushed with bronze. Spindles are of forged, high-carbon steel, accurately ground

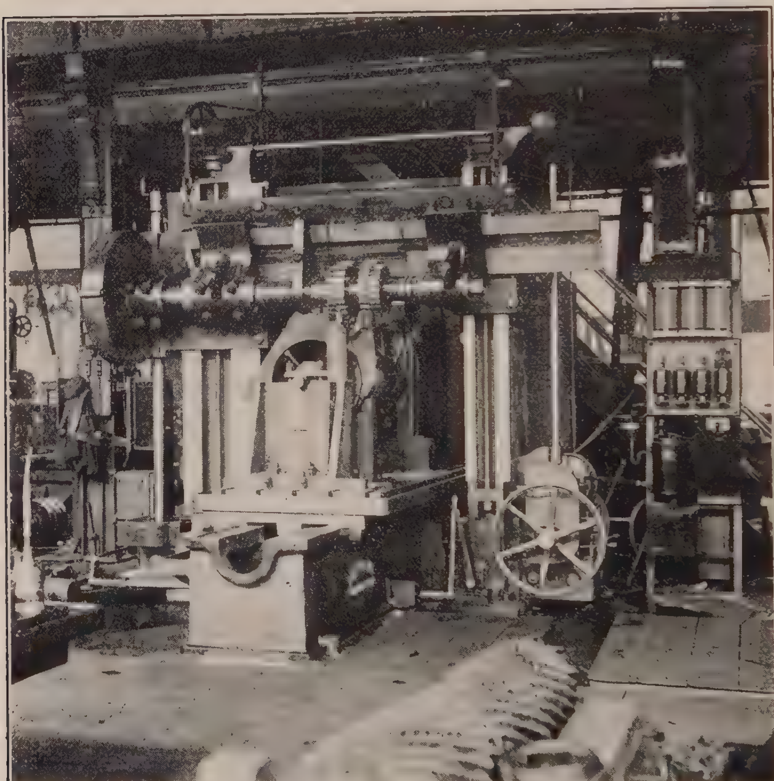

Fig. 6. Example of Heavy Milling.

and fitted with ball thrust-bearings, instead of the fibre washers previously used. Automatic time-saving devices have received much attention. Attachable multiple-drill heads, having adjustable centers arranged to take 2, 3, 4, 5 or 6 drills, have found many suitable applications. High-speed drills have encouraged the practice of multiple drilling, and, on repetition work, multiple-drilling machines are often arranged to drill

complete at one setting. Such machines may be arranged for drilling in five or more directions at one time.

GRINDING AND GRINDING MACHINES.

Since Mr. E. G. Acheson produced the substance known as Carborundum, about 25 years ago, investigators and manufacturers of abrasives have given great attention to the grain, grade and bonding of their products, with the result that today we have abrasive wheels and discs of emery, carborundum, aloxite, alundum and crystolon in great variety of size, shape, grain and grade, of superior quality, and adapted to a wide range of service.

The demand for accurately finished parts of machinery at a low cost has been largely responsible not only for the development in abrasives, but also for the great improvement in grinding machinery. Since manufacturers of machinery began to realize that abrasive discs and wheels were truly cutting instruments, in which innumerable cutting points and edges were presented to the work, much work that was previously performed on millers, planers and lathes has been transferred to the grinders.

Dry Disc Grinding Versus Milling.

Considerable saving is being effected by the use of disc grinders on many flat surfaces that were formerly milled. This is more noticeable in dealing with castings that are liable to be chilled and brittle. Grinding also possesses decided advantages where the shape of the casting or forging is such that, in order to prevent springing, great care is necessary in chucking or clamping the work in the milling machine.

Motor driven, double disc grinders are in use, in which the discs are of steel, 23 inches (584.2 mm) diameter and running at 1450 revolutions per minute. The abrasive circles are glued to the discs by a cold glue, which is readily soluble in water. When the abrasive circle becomes somewhat worn, it may be used on the corners or edges of work or upon work which presents surfaces of comparatively small area, and when worn out, the abrasive circle may be removed from the steel disc by immersion in a tank of warm water. As disc grinders of this kind are invariably dry grinders, they must be con-

nected up with a dust extracting system, and on account of the dust, it is not considered good practice to install these machines near other machinery.

In another type of disc grinder, two constant-speed motors are used, one of which is fixed on the bed, while the position of the other is adjustable along the bed by means of rack and pinion. The spindle of this latter motor, together with its grinding disc, is adjustable in a longitudinal direction and may

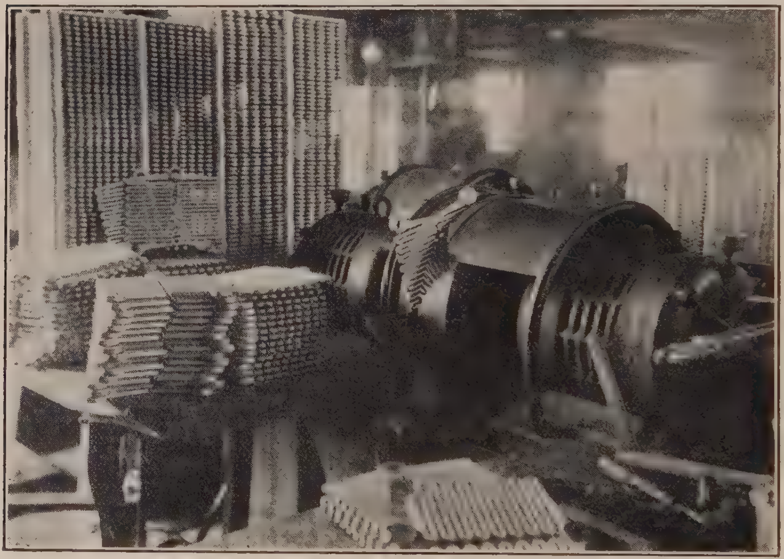

Fig. 7. Disc Grinder and Cast Iron Grids.

be controlled by a micrometer stop. By this means, work having parallel surfaces may often be rapidly and accurately finished. Fig. 7 shows such a piece of work in such a machine. Each of the three bosses, seen in the figure, is 1½ inches diameter by ½ inch thick (38.1 by 12.7 mm) and the finish requirements call for the thickness to be held within a limit of 0.001 inch (0.0254 mm). The grids shown are of cast iron and are finished on the bosses at the rate of 45 grids per hour.

Instead of the abrasive circles mentioned above, ring wheels may be used with advantage for roughing off scale and stock which are too rough to be ground economically by abrasive

cloth circles. There is another advantage possessed by the ring wheel, in that the life of the wheel is much longer than that of the abrasive circle. The case of the grid cited above furnishes a good example of the relative wear of circle and wheel. Wheels of 15 inches (381 mm) outside diameter, 9 inches (228.6 mm) inside diameter and 3 inches (76.2 mm) thickness were used instead of abrasive cloth circles, and it was found that each wheel was worn down $\frac{1}{16}$ inch (1.59 mm) on the face after

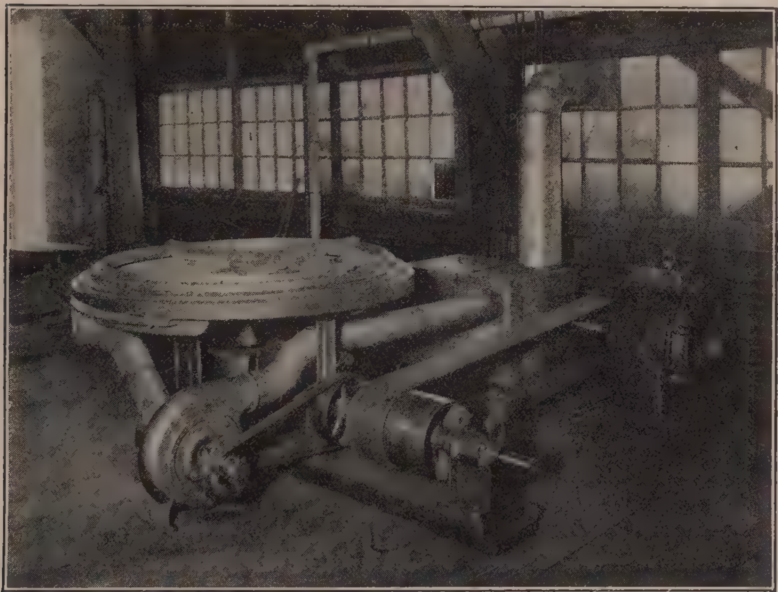

Fig. 8. Horizontal Disc Grinder.

one month's work; whereas, two abrasive circles are usually worn out by 4 days' work.

Another form of dry disc grinder, in which the disc is 48 inches (1.219 metres) diameter and rotates at the rate of 400 r.p.m. in a horizontal plane, is shown in Fig. 8. This machine represents the most recent addition to the family of dry disc grinders, and is remarkably efficient on certain kinds of work. Its chief peculiarity lies in the fact that the work bears directly on the abrasive and is ground by the pressure exerted by its own weight, hence, frail castings which are difficult to machine

on the milling machines because of the tendency to spring while being clamped, may, in many instances, be faced truly and economically by this process, which requires comparatively unskilled labor. Figure 9 is taken from castings which have been faced by the horizontal grinding process, and the following table shows the savings due to this method:

Name of Piece	Operation	Time on Milling Mach.	Time on Grinder	Time Saved Each Piece
Junction Box, "A"	Face	16 min.	3 min.	13 min.
Controller Base, "B"	Face bosses	10 "	3 "	7 "
Half Bearing, "C"	Face joint	7 "	1¾ "	5¼ "

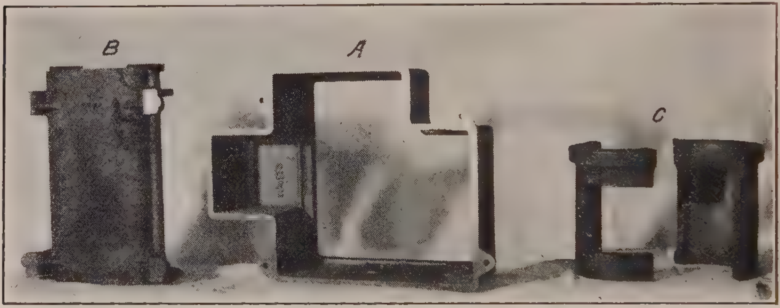

Fig. 9. Castings Ground on Horizontal Disc Grinder.

Wet Grinding.

For the production of true flat surfaces on hardened-steel punches and dies, the vertical surface grinder has been found highly efficient. A cup wheel 16 inches (406.4 mm) in outside diameter, running at a constant speed of 1000 r.p.m., is used. The work is held and presented to the wheel by means of a strong magnetic chuck, which forms the machine table; this latter has six different speeds of rotation. The feed mechanism is so graded as to allow of feeds ranging from 0.0002 inch (0.005 mm) to 0.005 inch (0.127 mm) in increments of 0.0002 in. (0.005 mm). A sheet iron guard surrounds the wheel, and splash guards prevent the cutting compound from being thrown beyond the machine.

Much of the work now done on the vertical machines was formerly done on grinders of an old type, having horizontal spindles and cylindrical wheels. The superiority of the vertical machine is due chiefly to the adjustable feeds and speeds, also

to the method of chucking, and face contact instead of line contact of the wheel.

In the up-keep of wheels, the vertical grinder costs five times more than the obsolete horizontal machines mentioned above, but since the vertical grinder produces from 50 to 75 per cent more work, the wheel cost per die is very little more. On small dies, having surfaces up to, say, 3 inches by 6 inches (76.2 by 152.4 mm), the saving due to the vertical machine is about 75 per cent; on large dies up to 30 inches (762 mm) dia. (the maximum capacity of the machine), the saving is about 50 per cent.

Cylindric Grinding:

The finishing of cylindric surfaces on cast iron and steel by grinding has been a well established machine shop process for many years. It is common practice on shaft grinding up to 6 inches (152.4 mm) diameter to use wheels of 2 inches (50.8 mm) face, and to give a work traverse of from ½ to ¾ of the wheel width per revolution of the work. With the correct combination of work and wheel speeds, wheel grain, grade and material, each pass of the wheel, when roughing, may remove from 0.003 to 0.004 inch (0.076 to 0.102 mm) from the diameter of the shaft. At the end of each stroke, or pass, the longitudinal movement, or traverse, is suspended, while the work makes from one to two revolutions. The total number of passes required to rough grind any fit, therefore, depends on the amount of stock which has been allowed for grinding. This allowance varies considerably in different machine shops according to the class of work, the condition of the roughing lathes and the inspection of the rough-turned shafting. In general, however, the amount allowed for grinding depends on the diameter and the length of the work, and tables have been constructed which give this allowance for any shaft or given diameter and length. From what has just been said, it is evident that a considerable reduction in grinding time may be effected by increasing the width of wheel. In the latest development of cylindric grinding, which someone has called ''slabbing'', the advantages of the very wide wheel are obtained. This new method appears to have possibilities which are limited only by the width of the grinding wheel and the rigidity of the machine. Fig. 10 shows the application of the

"slabbing" process to a shaft 1.4 inches (35.56 mm) diameter by 30 inches (762 mm) long; from which it will be seen that, with the exception of one fit, the wheel exceeds the length of each shaft fit. By this means, the end traverse of wheel or work is in a large measure eliminated, and a corresponding decrease in grinding time realized.

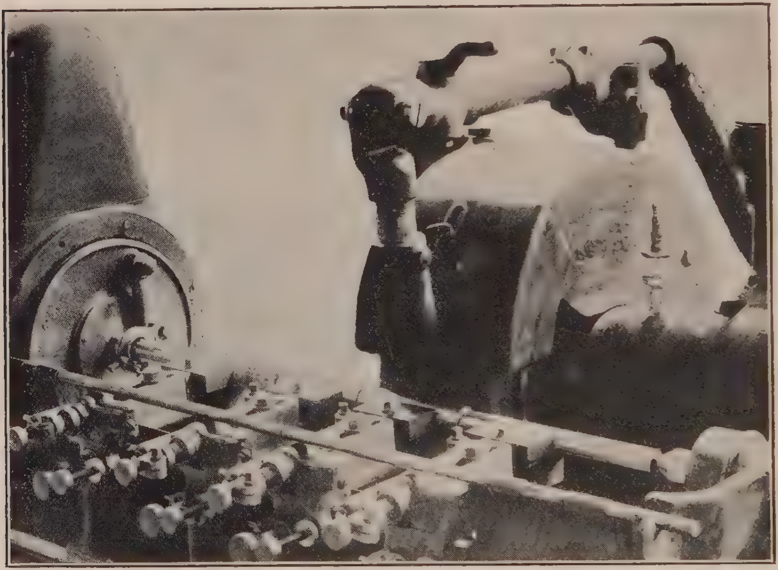

Fig. 10. "Slab Grinding" a Shaft.

FILE SHARPENING.

Although for a number of years attempts at file sharpening have been made, it is only within the last few years that the process has become a commercial success. A sand blasting apparatus is being used for file sharpening, with success, by several large manufacturing establishments. This apparatus consists of a sheet-iron chamber provided with uptake, settling tank, slurry mixing-tank, slurry overflow-pipe, air agitating pipe and slurry projector. A door gives access to the inside of the chamber. The slurry projector is inclined to the horizontal at an angle of 25 degrees, and the nozzle extends slightly within the chamber. This projector consists essentially of a bronze body to which are fitted steam pipe, slurry suction-pipe and nozzle. The steam supplies sufficient water for the slurry.

The files are sharpened by being held in the slurry jet in such a manner as to expose the backs of the file teeth to the cutting action of the sand. After the file has been sharpened, it is cleaned and dried by the steam, after the slurry supply has been cut off by a foot lever.

Success in file sharpening depends on the skillful selection of the files to be sharpened, maintenance of the correct angle between files and jet while sharpening, and the selection of a suitable sand. Experience shows that a sharpened file often does as much work as a new one, and the cost of sharpening averages about one-fifth of the cost of new files. The following results have been obtained under ordinary manufacturing conditions and may be taken as representative of the economies which are effected by the efficient use of this apparatus.

No. of Files Treated	Size	Total Cost Sand Blasting	Recut Price	Price of New Files
109	4 in. files	$ 0.88	....	$ 11.99
1245	6 " "	9.96	....	136.95
1333	8 " "	14.20	....	199.95
943	10 " "	15.07	$56.00	169.74
1206	12 " "	28.98	96.48	241.20
831	14 " "	26.69	99.72	174.51
566	16 " "	22.64	90.56	124.52
143	18 " "	6.28	27.17	34.32

ELECTRIC DRIVING OF MACHINE TOOLS.

That the electrically-driven machine shop possesses advantages, is evident from the rapidity with which electric driving has been substituted for mechanical driving. Among the advantages claimed for electric driving are the following:

Power may frequently be obtained from a public supply corporation at a less cost than would be possible were it generated in a private power station. In such a case the first cost of a private generating plant is unnecessary.

Where an electrically driven shop, having its own power station, is in the vicinity of a public supply system, power may be obtained for machine shop purposes when the private station is idle.

Where electric driving is used, the position of the power house may be determined by a convenient source of fuel and water supply and facilities for the disposal of ash; whereas,

mechanical transmission usually makes a definite relation of machine shop and power house imperative.

Transmission shafts, counter shafts, fixings and belts, with their expensive delays and repairs, are eliminated. As a result of the elimination of belting, there is less obstruction to light.

Electrically driven machinery may usually be more easily arranged to suit the sequence of manufacturing operations, and where the machines are individually driven, any machine may be operated irrespective of others. Closer and more conveniently obtainable cutting speed regulation, with a consequent increase of from 15 to 25 per cent in output, together with a great reduction of moving parts, is usually made possible by the substitution of electric for mechanical control of machine tools.

Great improvements have been made recently in the design and construction of machine shop electrical equipment. Motors have been reduced in weight and increased in mechanical strength by the substitution of pressed steel for cast iron and cast steel. Automatic starters and controllers have been improved and are now used to advantage on machines which are frequently started and stopped.

Among the advantages secured by automatic control—sometimes called "push button" control—may be cited the following:

Simplicity and safety in operation
Speed regulation to suit the hardness of material to be cut
Protection of motor from excessive starting current
Protection of motor from overload.

Convenient location of the push buttons greatly facilitates the setting up of work on the machine. This feature is highly desirable for planers and boring mills. A very full description of automatic control for industrial motors may be found in the Electric Journal of December, 1914.

It frequently happens that existing machine tools may be readily altered and greatly improved by the substitution of electrical for mechanical control, as in the following case: A lathe, in which the work speeds were obtained through numerous spur gears, clutches, levers and fittings, had caused considerable expense and delay due to repairs, and it was decided that a change from mechanical to electrical control should be

tried, as a possible means of reducing the repair bill. Fourteen spur gears, two double clutches and their levers and fittings were removed from the headstock and an adjustable speed motor and controller were installed. After the change, instead of the nine original speeds, thirty-two were available under the new conditions. In addition to the advantages of closer speed regulation and reduction of wearing parts, an appreciable reduction in power used is recorded, and speed changes are obtained with less effort.

From what has been said with reference to modern cutting tools and machinery, it is evident that rapid advances have been made in machine shop methods and equipment; it is also a fact that the cost of equipment has increased greatly. Also, the first cost of buildings, with the superior hygienic conditions under which men work; the increased cost of management due to the more highly developed and complex manufacturing conditions and competition; and other items connected with the production of machinery, all combine to swell the total overhead factory expense. Under these circumstances, it is essential that a high state of efficiency be maintained in the machine shop, and this can be secured only when the machinery is kept running at or near its maximum capacity. There are many factors involved in the realization of this latter condition, not the least of which is the ability of the machine tool operator; and in order that the operator may work to the best advantage, it is now customary, in large organizations where a great many tools are used, to employ a staff of expert demonstrators, whose business it is to instruct operators and demonstrate the capabilities of machines. The demonstrator is also expected to keep himself abreast of the latest developments in his class of work, and to devise means for simplifying and improving machining operations. The paper read by Mr. G. O. Gridley on "Safe Selling Guarantees" before the National Machine Tool Builder's Association, in the fall of 1913, brings out very forcibly the benefits to be derived by machine tool builders from the demonstration of the value of their machinery.

The buyer of machinery is naturally influenced by the design and workmanship in the tools offered, but, generally speaking, his final decision in making a purchase will rest upon the quantity and quality of the work which the tools will produce

in a definite time and under working conditions which are conducive to a reasonably long period of usefulness and efficiency. Therefore, the machine tool builders who are in a position to study the requirements of their customers and to furnish data as to how work should be done and the time in which the work can be done, have decided advantages over those who do not render such service. The market now offers a great many

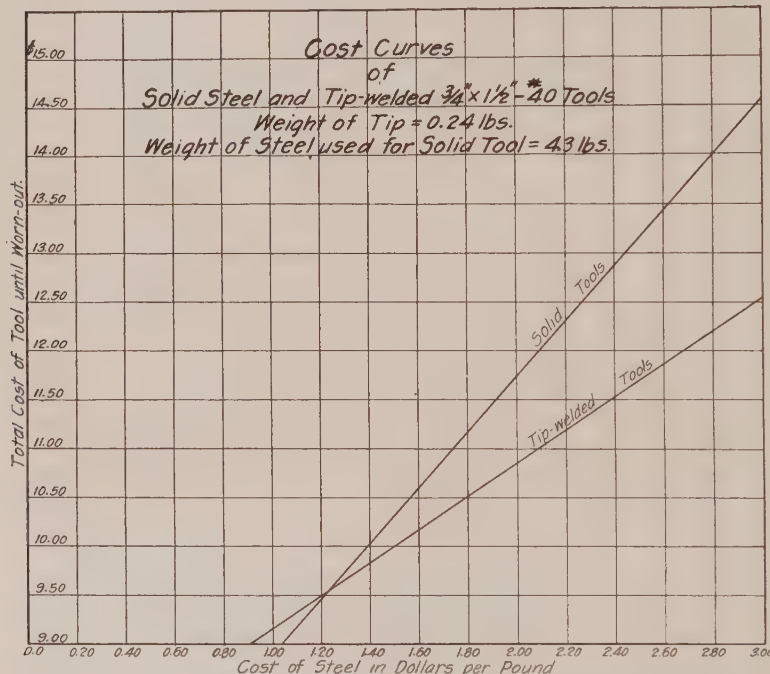

Fig. 11.

competitive machines for doing practically the same class of work, and it is not to be expected that the users can always accurately decide what is best for their requirements.

Before making a guarantee that a machine tool will perform a definite piece of work in a certain time, the builder of the machine should be in a position to demonstrate that the work can be performed in the time specified; otherwise, it is unsafe to make such a guarantee. Actual demonstration is convincing, and its influence as a selling agent is very far reach-

ing. Demonstration provides a means of obtaining the most suitable arrangement of tools and the best combination of feeds, speeds, and cuts for the work in hand. During a demonstration, an itemized record, or time study, can be made of the operations, the material, the cutting feeds, speeds or cuts, the handling time and the time consumed in manipulating the machine. Such records, when conveniently filed, form a valuable source of information, which may be used to advantage when estimating the cost of similar work.

DISCUSSION

Mr. Carl G. Barth,* Mem. Am. Soc. M. E., stated that the use of welded high-speed steel points on carbon-steel tools did not work out as to relative costs as determined by Mr. Norris. He had made a number of experiments on welded tips, and as he treated them they gave a more efficient tool. He had taken the tail end of a solid tool, using it as a tip and got a great deal more efficient tool in each case. Mr. Barth.

With reference to the statement that belt feeds were supplanted by positive feeds, he felt that all make mistakes by generalizing. He had rebuilt tools in a number of shops, and had made a specialty of belt feeds and got a perfect progression of speeds. If one makes two large cones of exactly the same size, or takes one and cuts it in two, putting one above and one below, an absolutely arithmetical progression of speeds can be obtained. The trouble with belt feeds is generally due to using too small belts. In England, they are putting in belt feeds with large belts.

As to the use of bronze bushings, he stated that they were a mistake, as they gave trouble. They had replaced them with cast iron bushings which gave no trouble.

He had used high-speed steel for lathe centers with great success and advantage.

He felt that there was too much buying of fast-moving machinery, which was too expensive.

The range of feeds and speeds of drill presses on the market was altogether too limited. By rebuilding a drill press they had obtained a much better press than any on the market.

He had been the first to want feeds of millers independent of revolutions. Scientifically, there should be a proper feed for every tooth in the cutter. We should have ''feed per revolution'' and ''feed per minute'', and should be able to get the same ratio of feed per revolution at all speeds.

Manufacturers put on their machines data of the speeds and feeds they tried to get, rather than of the ones they actually got. What is needed is to get at the ratio expressed in per cent rather than in minutes.

* Cons. Engr., Philadelphia, Pa.

Mr. Barth. It is highly desirable that all tool manufacturers should agree upon the mathematical ratios for feeds, speeds, etc., and make their use universal.

A man may study out a drill-press job for one particular machine, but other machines may be different. It should be possible for a man to learn one drill press with its speeds and feeds and their application to all classes of work; then when he is familiar with one press, he would be familiar with all.

Mr. Hartness. **Mr. James Hartness** stated that they were doing their best to get their speeds and feeds to the slide-rule system of Mr. Barth, but invention comes first, then they have to check up their work at the last and cannot always work like a slide-rule.

Mr. Norris. **Mr. E. R. Norris** (by letter) in replying to Mr. Barth said that the solution of the question on relative costs of "solid" and "tip-welded" tools must depend largely upon the cost of the high-speed steel tip which is welded to the carbon-steel shank. Recent advances in the cost of high-speed steel have compelled us to investigate very thoroughly this question of relative costs. Figure 11 gives the results of our investigations with a tip-welded tool having a tip weighing 0.24 lbs. in the rough. Ordinates in this diagram show the factory costs, which include all dressing, grinding, welding and hardening expenses incurred in upkeep during the life of one tool, and an allowance for salvage on the worn-out tool. The total number of grindings received by the solid tool equalled the total number received by the tip-welded tool.

On referring to the diagram, it will be seen that under the conditions stated, the use of tip-welded tools becomes economical when the cost of high-speed steel exceeds \$1.20 per lb.

With regard to "taking the tail end of a solid tool and using it as the tip", we entirely agree with the remarks, as a heavy tool will almost invariably do more efficient roughing duty than will a light one—other conditions being equal.

While recognizing the fact that belt drives are desirable under certain conditions where large belts may be used, it is our experience that belt-driven feeds have been largely superseded by spur-geared feeds where positive, compact and readily changeable feed mechanisms are required.

Bushed bearings are desirable for several reasons, one of which is that when a bearing is worn the bush may be driven out and another put in with a minimum loss of time, and the original alignment secured where bearings are connected by rigid frame-work, such as we find in most kinds of machinery.

With regard to the merits of bronze and cast iron bushes, we find cast iron bushes giving excellent results where the wearing surfaces are ample for the pressure sustained and where care is taken to get and keep the wearing surfaces in good condition. We also find that bronze bushes give excellent results when properly used; they will stand more neglect than cast iron bushes, and if by accident they are allowed to run dry, they are not so liable to damage the journal.

Paper No. 120

"AUTOMATICS".

By

RALPH E. FLANDERS, Mem. Am. Soc. M. E.
Mgr. Jones & Lamson Machine Co.
Springfield, Vt., U. S. A.

The term "Automatic" (meaning, from derivation, "self-moving") is a relative one in its general use. From an early period lathes and, later, drilling machines have been provided with self-actuating feeds; they are thus "automatic" to that extent; and it is not so many years ago that the term disappeared from descriptions of ordinary machine tools. As self-actuating feeds became the rule rather than the exception, something more was required to justify the use of the term. It has of late years only been applied to machine tools in which practically all the movements are self-actuating.

Thus not the feed motion alone, but the return of the tool to its starting point, the bringing of new tools into position for cutting, the changing of speeds and feeds, and the starting and stopping of the machine, are among the features which entitle a machine tool to be called "automatic" in the present meaning of the word, when these various functions are self-performed by the mechanism, without any interference by the operator after the preliminary adjustment. In extreme cases of automatic action the mechanism also measures the work and adjusts the cutting tool, inserts the work in the machine and removes it after completion, and even transfers the work from one machine to another.

In American shop parlance, the term "automatic", used as a noun, has a more restricted meaning than given above. It usually denotes a machine belonging to the lathe family, such as an automatic screw machine or turret lathe. Particular atten-

tion will therefore be given to these machines, though not without first reviewing progress in the broader field. In the first place, descriptions will be given of certain machines selected to illustrate the various types of automatics.

AUTOMATIC ACTION APPLIED TO STANDARD MACHINE TOOLS.

The punch press is often equipped with an intermittent roller feed, for cutting out and forming work from a continuous strip or ribbon of metal. The machine operates continuously and without attention until the stock is all used up, and thus furnishes an example of true automatic action. A later development is the application of the "dial feed" to the punch press, in which an intermittently rotating disk or dial carries the blanks to be operated upon to the die, or even through a series of dies, so that complicated punching, forming and drawing operations may be performed in one machine. The operator's duty is to keep the dial supplied with blanks. The machine itself usually ejects the finished work. With the dial feed, the operator can often, and with the roller feed usually, tend more than one machine; and there is the added advantage of safety in operation over hand feeding.

An interesting case of automatic action in this class of machinery is the equipment furnished for making tin cans for preserving fruits and vegetables. Here the sides and cover are cut out, formed, fluxed and soldered together practically without the assistance of the operator, although attendance is required for inspection of the finished work and adjustment of the mechanism. This is an example of the extreme case of automatic mechanism, in that the equipment comprises what is really a group of machines, with mechanism for carrying the work from one machine to another and assembling the separate parts into the complete product.

An important recent development in milling is the use of the vertical milling machine with a continuously rotating table, as shown in Fig. 1. This table is provided with a series of fixtures about its periphery, holding a circular row of pieces to be milled. These pieces are located close together, so as to make the surface to be finished as nearly continuous as possible. The

operator stands in front of the rotating table, takes out the finished work as it leaves the cutter and replaces it with work to be machined. The mill thus cuts without intermission, there being no stopping and running back of the table to change the work.

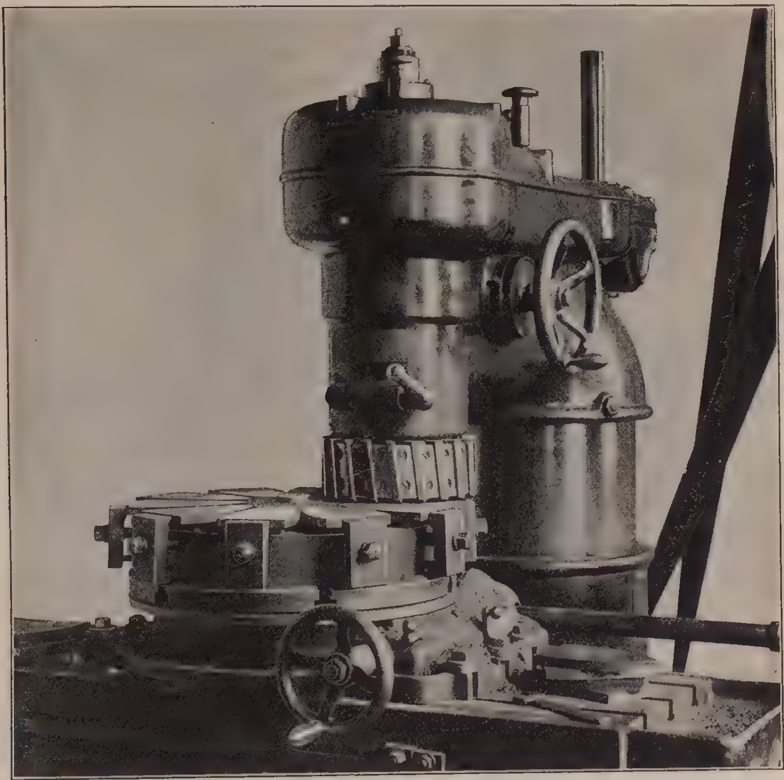

Fig. 1. A Brown & Sharpe Vertical Miller fitted with Constantly Rotating Work Table and Series of Jigs for Continuous Milling. Work is changed without stopping Rotary Feed.

A recently developed automatic milling machine is shown in Fig. 2. In the form shown, it is a modification of the Lincoln type of miller, largely used in the interchangeable manufacture of small arms, typewriters, sewing machines, etc. It is also furnished as a single- or double-head face milling machine. The

automatic feature is the control of the longitudinal feed of the table. By an ingenious arrangement of stops and connected mechanism, it may be set for any one of the various series of movements given below.

a. Table feeds rapidly until cutter approaches work, then slows down to cutting feed, either stopping at end of cut or returning quickly to starting point as desired.

b. Same as above except that fast motion may be thrown in momentarily to carry the cutter past open spaces when the surface to be milled is intermittent instead of continuous.

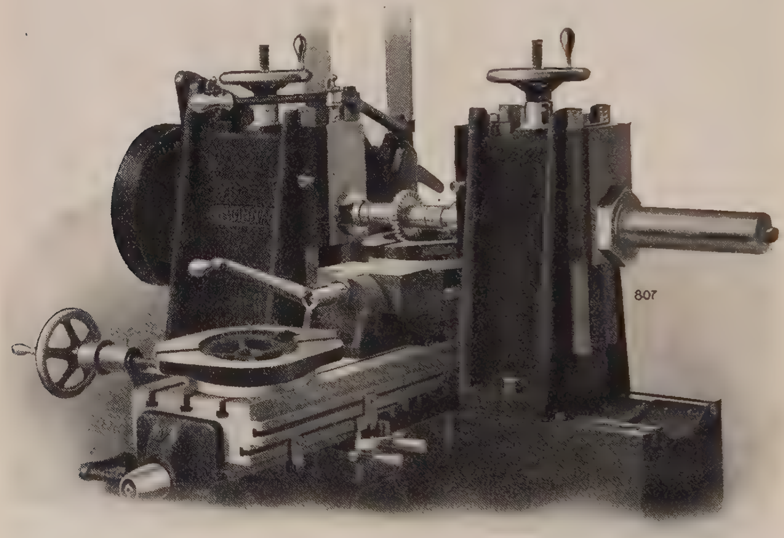

Fig. 2. Cincinnati Automatic Milling Machine. Provided with Self-acting Control of both Rapid Traverse and Working Feed, as well as Quick Return. In case shown, Feed is automatically speeded up while Cutter passes open space in center of work, of which sample is shown, lying on end of Work Table.

c. With work held in vise or fixture at each end of table, table moves rapidly until cutter approaches work, then slows down to cutting feed, stopping at end of cut; meanwhile work has been changed at other end of table. A touch of the control lever runs the table rapidly back until cutter approaches work at other end, then the slow feed throws in until the completion of the cut, when the feed stops. Meanwhile the work at the

first end of the table has been changed, and the cycle is repeated. Various other combinations are possible. This mechanism permits increase of output by the reducing of idle time, by saving the operator from fatigue, and sometimes by permitting him to run more than one machine.

A more elaborate automatic milling machine has recently been brought out by Potter & Johnston, in which two complete

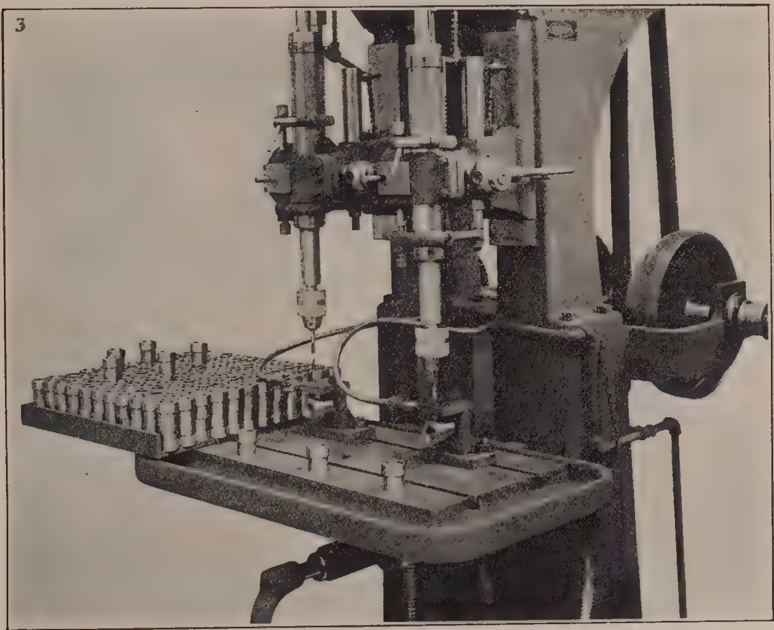

Fig. 3. Avey Drill with Automatic Feed; all motions self-acting, so that the operator does nothing but change the work.

work tables are provided. The work on one of these tables is being milled while that on the other is being changed. At the conclusion of the cut the tables change places. Milling is thus practically continuous.

Automatic control applied to a light drill press is illustrated in Fig. 3. The design of this mechanism is such that the machine may be operated fully automatically, semi-automatically or as plain hand-feed machine. In the full-automatic type, all the movements of the spindle are automatic; all the operator

has to do is to change the work between strokes, operating as many spindles as the nature of the work will allow. The semi-automatic is that type in which the tripping of the feed and the return of the spindle are automatic, but the feed must be re-engaged by hand. Here the operator needs time to arrange his work under the spindle. When ready, he re-engages the feed and goes to the next spindle doing the same, and so on for as many spindles as he can take care of. Each spindle in turn drills to the pre-arranged depth, trips, returns and stops. The plain hand-feed is obtained by merely throwing out the automatic features. When the automatic, or semi-automatic feed is in use, the feed is by worm and worm wheel, and the quick return is by weight, checked by an air dash-pot at the top of the stroke. Quick-acting jigs are necessary for getting the full advantage from a machine of this type. The number of spindles an operator can keep going is limited only by the rapidity with which he can change the work. Convenience in the supply of work is also a factor. Both points are well illustrated in Fig. 3.

Gear-cutting machines, completely automatic except for changing the work, have been in use for many years. The developments of the past decade in this line consist in the extension of automatic action to the generating of bevel gears, and to the development of various new methods of gear cutting, in which the automatic feature is, however, no more elaborated than in the older methods.

For cylindrical grinding of small pins and studs in large quantities, various manufacturers have occasionally supplied grinding machines with complete automatic control. The operator places the work in a hopper or magazine, as the machine is completely self-feeding. The attendant inspects the work occasionally and adjusts the wheel as necessary to compensate for wear. He also trues it with the diamond when required. Otherwise, the grinder is completely self-acting.

AUTOMATIC SCREW MACHINES.

With the introduction of the original Spencer automatic screw machine in the early eighties began the extensive use of "automatics" as an important factor in modern machine-shop

practice. This machine was simply a small turret lathe or "screw machine" fitted with a modified form of the Parkhurst wire or rod feed; but the various motions usually operated by hand were controlled instead from various cams on a single cam shaft, extending under the machine for its whole length. Changes in feed and length of cut were made by changes in simple strap cams. The time taken for the idle movements was shortened by giving a quick movement to the cam shaft, automatically changing to the slow feeding movement when the cut-

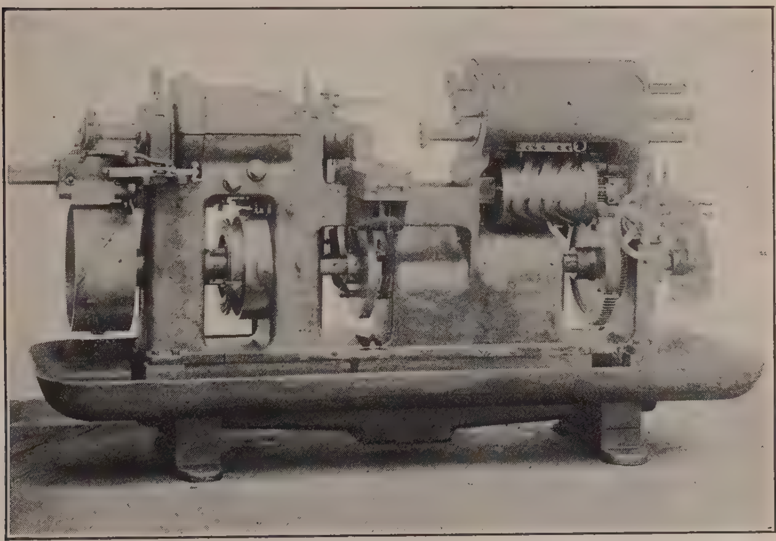

Fig. 4. A Modern Version of the Spencer Type Automatic Screw Machine, built by the Hartford Machine Screw Company.

ting tools approached the work. Machines of practically the original design are still in successful use, and one or two firms, notably the English firm of Alfred Herbert, Ltd., have brought out modernized variations of the original design, which rank with the most successful machines of their kind.

A recent American example, showing descent from the Spencer machine, is the Hartford Automatic Screw Machine illustrated in Fig. 4. The original standard turret is changed for a turret of the barrel type, and the change of feeds is facili-

tated by the multiple-track cam shown beneath the turret. See also the Cleveland Automatic, illustrated in Fig. 19, and described later.

The first machine to break away from the Spencer type was the Brown & Sharpe, shown in its latest form in Fig. 5. This

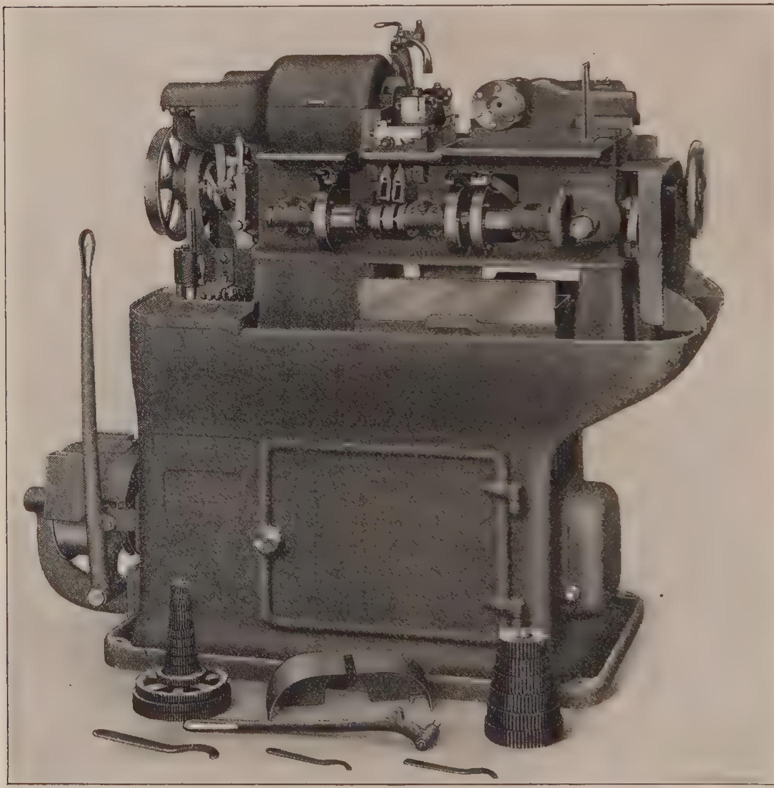

Fig. 5. Brown & Sharpe Automatic Screw Machine. This design has Single-Pulley Drive, all the various connections for Speed Changing, Reversing, etc., being contained in the Base instead of in a complicated Overhead Countershaft.

automatic employs disk cams, which are usually special for the particular piece being made. Unlike the Spencer machine, these cams have a rotating motion at continuous speed, all the idle movements being operated by intermittent clutch connections with a fast-running lay shaft. The machine is remarkable for

its accuracy, and for the quickness of its motions—an important point in small work. It has been built in great numbers and is familiar to all screw-machine specialists. The machine illustrated is of the single-pulley-drive type. As is the case with most of the modern machines, it may be fitted with various automatic attachments for milling, cross milling, screw slotting, etc.

The original field of the automatic screw machine was, as its name implies, the making of screws. This was quickly en-

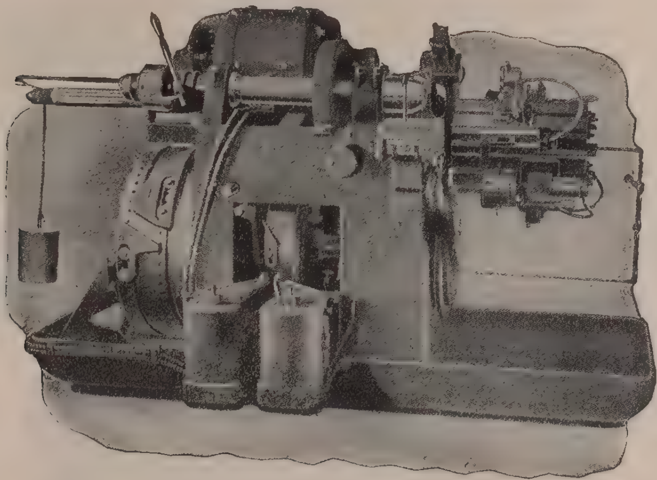

Fig. 6. The Gridley Automatic Screw Machine, especially adapted to making Bolts, Studs, Short Shafts, etc. Note the Automatic Change of Speeds and Feeds by Self-acting Electric Controllers. The Feed and Spindle Drives are operated by separate Motors for this purpose.

larged to take in the making of all varieties of small nuts, washers, pins, collars, etc. The Gridley Automatic, shown in Fig. 6, may justly claim to have led in the further extension of the field to the making of studs, shafts, etc., of several inches in length. The turret is of the drum type, with the tools mounted on long slides on its periphery. This permits long feed movements and the mounting of two or more tools in tandem. Machines of this type are doing a class of work that could previously only be handled on the small engine lathe, or on that type of turret lathe which is particularly designed for bar work.

While the machines just described have led in widening the field of the "automatic", there has been another line of development which has greatly increased production in those classes of work for which screw machines were first used. This is the multiple-spindle automatic screw machine, of which the National-Acme design, shown in Fig. 7, may be considered as representative. In this machine the turret is dispensed with, and its place is taken by a tool holder which feeds forward four or more tools to operate on bars of stock held in the same number

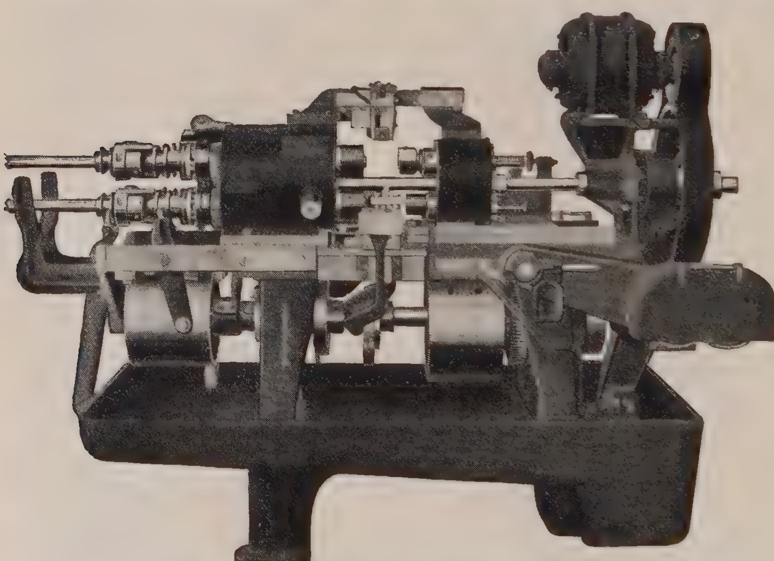

Fig. 7. The National Acme Multiple-Spindle Automatic, with Four Tool Positions, all working simultaneously on Four Bars of Stock.

of opposing work spindles. It is a drum or carrier containing these spindles which "indexes", instead of the tool holder or turret.

After the tool holder has concluded its working stroke and retired, the work spindle carrier is revolved, bringing each bar of stock to the next tool in rotation. The final tool position provides for a cut-off blade, and a complete piece is finished and cut off at each indexing. One or more forming slides are also provided at different positions. With this machine, of course, all the cutting tools are working on each feeding stroke, as each

has a bar of stock presented to it, instead of having to wait its turn on a single bar of stock.

The Gridley Multiple Spindle Automatic is another well known machine of this type.

Among the other makes of multiple-spindle automatics, the Davenport machine, shown in Fig. 8, may be mentioned. It is

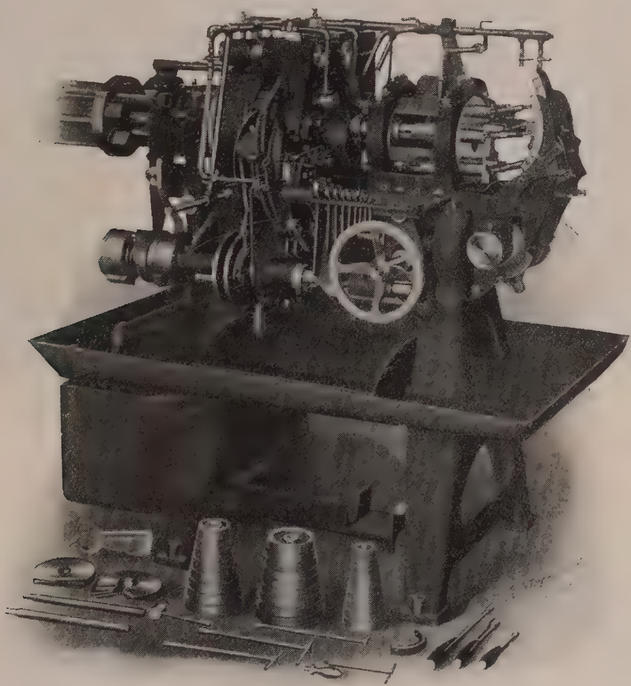

Fig. 8. The Davenport Multiple-Spindle Automatic, provided with close adjustments for Accurate Small Work. An Adjustable Link System covers a wide range of work with Standard Cams.

designed to combine the high output of the multiple-spindle machine with the accuracy of the high-grade single-spindle on small, close work. It also provides for separately adjustable feeding movements for the different tools, instead of feeding them all forward together in the same holder; thus tending to increase the output considerably. For ordinary work, the adjustments provided permit the use of standard cams.

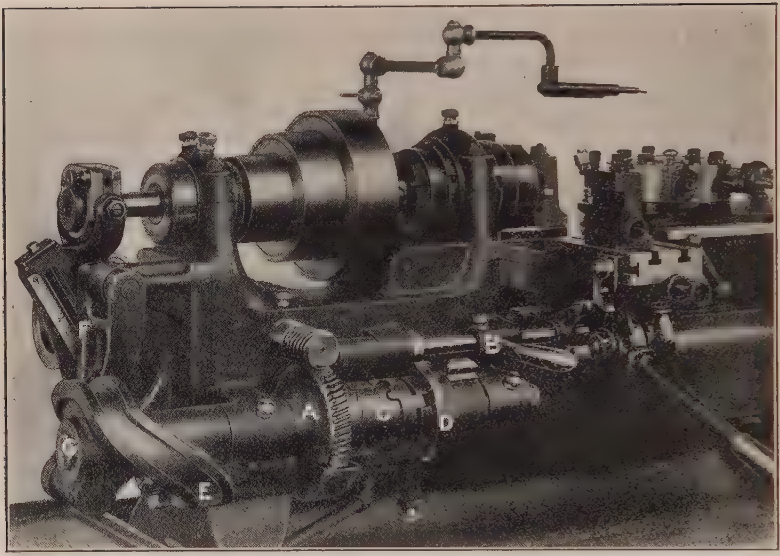

Fig. 9. The Brown & Sharpe Hand Screw Machine with Automatic Wire Feed; a simple example of the "Lay Shaft" Mechanism.

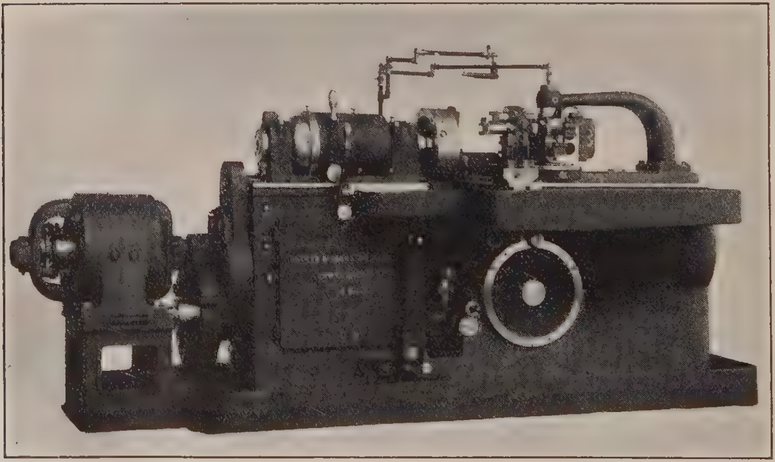

Fig. 10. The Potter & Johnston Automatic Turret Lathe for Large Work.

NOTES ON MECHANISM.

While this paper is not particularly concerned with problems of mechanism, it will be worth while to stop long enough at this point to note the various ways in which these problems have been attacked. The various forms of control that have been used for automatics are the following:

1. Direct cam control. See machines illustrated in Figs. 4, 6, 7, 10, 14, 15 and 19.

2. Cam control for feeds, and lay-shaft control for fast motions. See machines in Figs. 5, 8, 9 and 17.

3. Lead-screw control. See machines in Figs. 11, 12 and 16.

4. Hydraulic control, shown in Fig. 13.

5. Pneumatic control, in various small watchmaking machinery, and applied experimentally to larger automatics.

In changing feeds for different set-ups and different cuts in the same set-up, the following methods are in use:

1. Changing the cam, as in Figs. 5, 6, 7, 10, 14 and 15. In all these cases, however, the whole cycle of operations can be accelerated or retarded *in toto* by changing gears.

2. Changing gears for separate operations, in Figs. 11 and 12; or changing a friction drive, in Fig. 19, such changes are made automatically.

3. Setting adjustable link motions, in Fig. 8.

4. Changing capacity of pump, in Fig. 13.

Of these various schemes, that of the "lay shaft" is perhaps the only one that requires special explanation. A simplified application of this principle is shown on a Brown & Sharpe Automatic Wire-Feed Screw Machine in Fig. 9. The worm wheel A on the front of the headstock is given a constant rotation at a good rate of speed. The hand lever B operates a trip, which controls a single revolution clutch C similar to those used on punch presses. When this lever is operated, cam-shaft G is given a single revolution by worm wheel A. The attached cam D operates the chuck through an interior connection, while cam E feeds the stock through the link motion F, which is adjustable for the desired length of stock.

This principle of the lay shaft makes it possible to execute the idle movements with the greatest rapidity, leaving the slow-

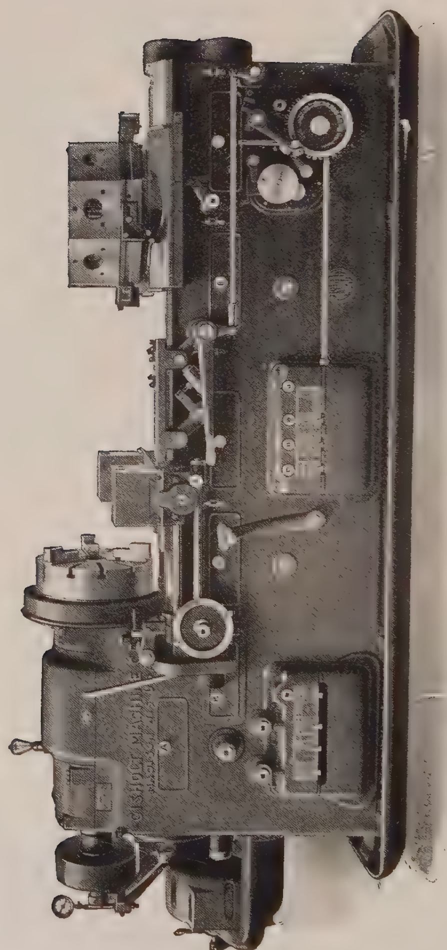

Fig. 11. The Gisholt Automatic Turret Lathe.

moving cams to control the feeding motions only. While shown in use in Fig. 9 on a hand machine, it finds a more complete use in the Automatic machines in Figs. 5, 8 and 17. It is, in general, a somewhat more complicated scheme than the simple cam-operated arrangement, but is less complicated than the lead-screw type of control.

AUTOMATIC TURRET LATHES.

The Potter & Johnston Automatic, shown in Fig. 10, deserves the credit of opening up the field of chuck work for automatic operation. While the automatic screw machine had been adapted in particular cases to the machining of small castings, such as sewing-machine balance wheels, there had been no serious attempt to use it in the general run of small- and medium-sized forgings, castings and chunk stock. The machine is a turret lathe in the strictest sense of the word, but with turret slide, cross slides, and feed and speed changes all controlled automatically by cams.

The Gisholt Automatic, shown in Fig. 11, is tooled in much the same way as the Potter & Johnston, and is intended for the same class of work. The mechanism is entirely different, however, as most of the movements are controlled by lead screws instead of cams.

The multiple-spindle screw machine has been noted. Paralleling this development in the screw machine, there has lately been a corresponding activity on the part of turret-lathe designers, resulting in what, for want of a better name, may be called a multiple-spindle automatic turret lathe. The Bullard "Mult-automatic", shown in Fig. 12, is an example of this type. It may perhaps be described as a series of small boring-mill tables mounted in a ring about a central column, and provided with mechanism for being indexed to successive positions under successive tool holders carried at the top of the column. The machine, while similar in principle to the multiple-spindle automatic, is vertical instead of horizontal, and is, of course, vastly larger, being designed for machining castings and forgings of considerable size. As each spindle or table returns to the first position at the front of the machine, the workman changes the completed piece for a rough one. Changes in feeds, speeds, etc., are made automatically for the different positions, and particu-

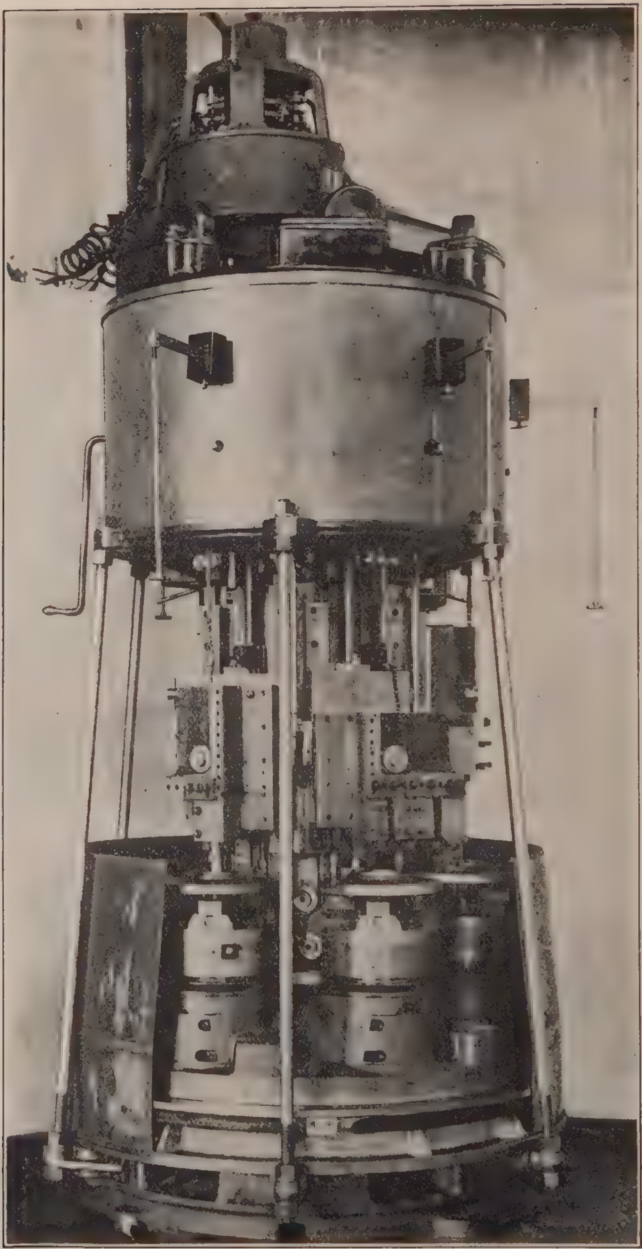

Fig. 12. The Bullard "Mult-automatic"—a Multiple-Spindle Vertical Machine for Turret Lathe Work.

lar care has been taken to so interlock the various independent mechanisms as to avoid all danger of interference and breakage.

The Conradson Machine, while similar to the machine just described in its general arrangement, is controlled by entirely different mechanism. The tool and work movements are similar, except that the Conradson machine uses side heads for facing,

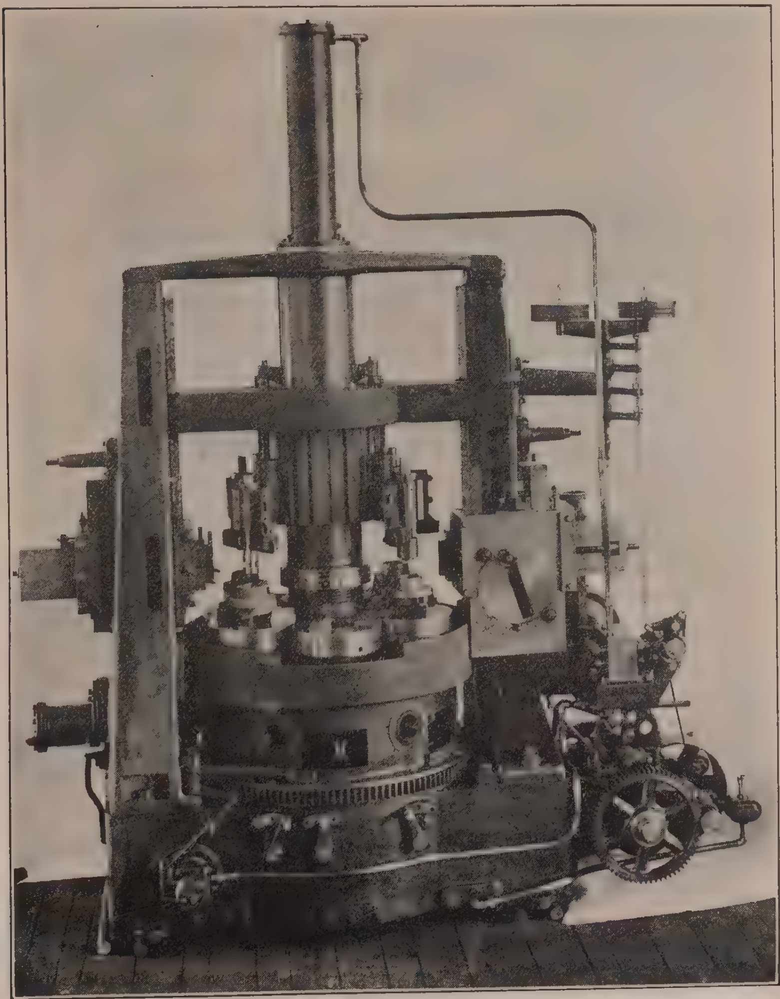

Fig. 13. The Conradson Vertical Multiple-Spindle Automatic, with Hydraulic Feeds and Control.

where the Bullard machine gives a cross feed to the regular tool holder. The control of the machine shown in Fig. 13 is, however, almost entirely by hydraulic pressure, oil being the medium employed. The feeding is by a differential scheme; the pressure for the return motion is on continuously, but is overbalanced by a pressure on a larger piston area for the forward movement. This arrangement is employed to give firm control and absence of backlash to the various movements.

The New Britain Automatic, shown in Fig. 14, is an older machine for somewhat similar, but smaller work. It is horizontal, and particularly adapted for such operations as drill-

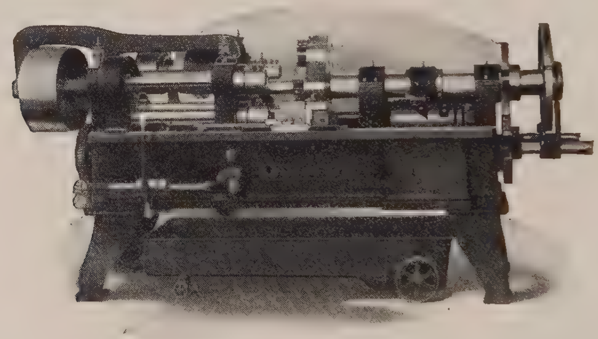

Fig. 14. The New Britain Automatic; a Multiple-Spindle Machine for Drilling, Tapping, Counterboring, etc., on small work.

ing, counterboring, facing, tapping, etc., the work being stationary while the tools revolve. The work is held in a series of vises or fixtures on an indexing plate, there being one station always free of tools, for changing work. This machine is also made in a double type, in which work is clamped in the middle and presented for tool operation on both sides.

AUTOMATIC LATHES.

There is still a further line of development which has resulted in what may be called, strictly speaking, the ''automatic lathe''. This type of machine has headstock and tailstock similar to the standard engine lathe, but with carriage and supplementary facing and forming tools automatically controlled. The

original machine in this field is the Fay Automatic Lathe, shown in Fig. 15. It is used for rough forgings which may be held on centers, such as automobile steering knuckles; but its principal use is for work held on an arbor. It is thus a second-operation machine, completing work that has previously been chucked and otherwise partly finished on the drill press or turret lathe. The machine is cam actuated, and provision is made for taper and form turning and bevel facing. The operator changes the work on an extra arbor while the machines are running, thus reducing the idle time of the machine to a minimum. The turn-

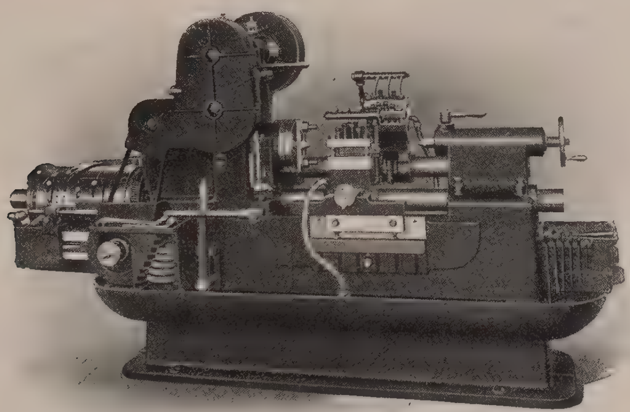

Fig. 15. The Fay Automatic Lathe for Finishing Work held on Centers; particularly Second Operation Work held on Arbors.

ing tools relieve automatically on the return stroke, so as not to score the work, and the machine stops itself at the conclusion of the cut. By using all the tools the work will stand, and by putting two or more pieces of work on the same arbor, when possible, a high rate of production may be obtained. There is also the advantage of the accuracy which comes from doing second-operation work on a true arbor, between true centers.

Another somewhat simpler machine for simple work of the same class is the Reed-Prentice Automatic Lathe, shown in Fig. 16. This lathe is also intended particularly for continuous running on the same work, without change of speeds or feeds. Instead of using cams, the feed is by regular lathe-apron mechan-

ism, released at the end of the cut and returned quickly by a weight.

The foregoing descriptions by no means include all the automatics in regular and successful use at the present time. Space limits and the intended scope of the paper do not permit a complete description and classification. The machines shown

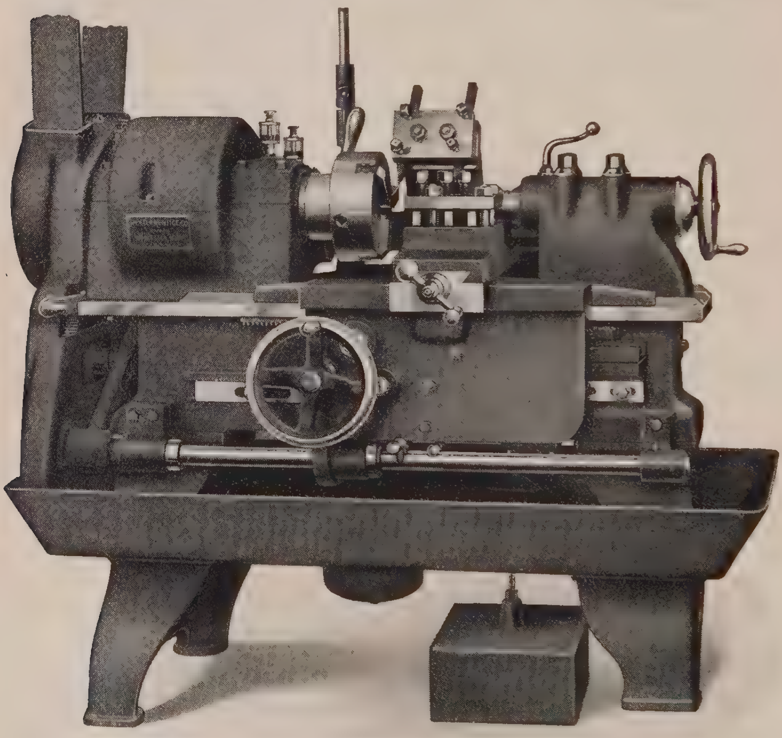

Fig. 16. The Reed-Prentice Lathe for Second Operation Work.

were selected for their value as illustrating various standard types, thus giving a ground work for the general description which follows.

TENDENCIES IN DESIGN.

From what has been said, it will be seen that the first step from the hand-controlled machines was in the direction of com-

paratively simple single-spindle machines, which were afterwards refined to give greater accuracy and output. The next step was the application of the multiple-spindle idea; this was tried first for work in which great accuracy is not essential, owing to the difficulties introduced by the multiplicity of bearings, and particularly by the great accuracy required in the indexing of the multiple machine. As expert attention has been more and more applied to these points, the multi-spindle machine has been found better adapted to work of the best quality.

As an example of this line of development within the walls of a single shop, the case may be instanced of one of the largest watch factories in the country. The turning of watch staffs was originally done in hand-controlled lathes, one lathe being set for one diameter, the next for the next, and so on. The sequence of cuts was carefully arranged so that the work should not be sprung by the cutting pressure in any operation, but should come out running true on all the various diameters. This requires frequent reversing of the work in changing from one cut to another. The next step was one which was comparatively simple, in itself, but marked a great advance in economy of production. A complete equipment of lathes for finishing one staff was arranged in order on one bench, and automatic means provided for transferring the work from one machine to another, turning it end for end in transit, when necessary. All the machines in the row are thus simultaneously at work, each on its own cut. At the conclusion of all the cuts, a series of transferring arms comes into play, moving each piece of work simultaneously to the next machine in order, putting a fresh blank in the first machine in the line, and depositing the staff from the last machine in the tray for finished work.

In a similar way, processes were developed for drilling, tapping, counterboring and recessing the watch plates. First, simple hand-controlled machines; next, automatic machines, automatically fed from magazines. Then a row of such machines, with transfer arms carrying the plates from one machine to another.

Such machines represent the highest point of development in single-spindle automatic design. With proper grouping they give, in fact, about all the advantages of multiple-spindle design, with the added advantage of great simplicity in the design

of the separate units. The writer understands, however, that later tendencies in this plant have been in the direction of the multiple-spindle principle for a considerable portion of its work.

As an example of the grouping in one machine of unrelated operations, the case illustrated in Figs. 17 and 18, is interesting. This is the Davenport Automatic Assembling Machine. It is a

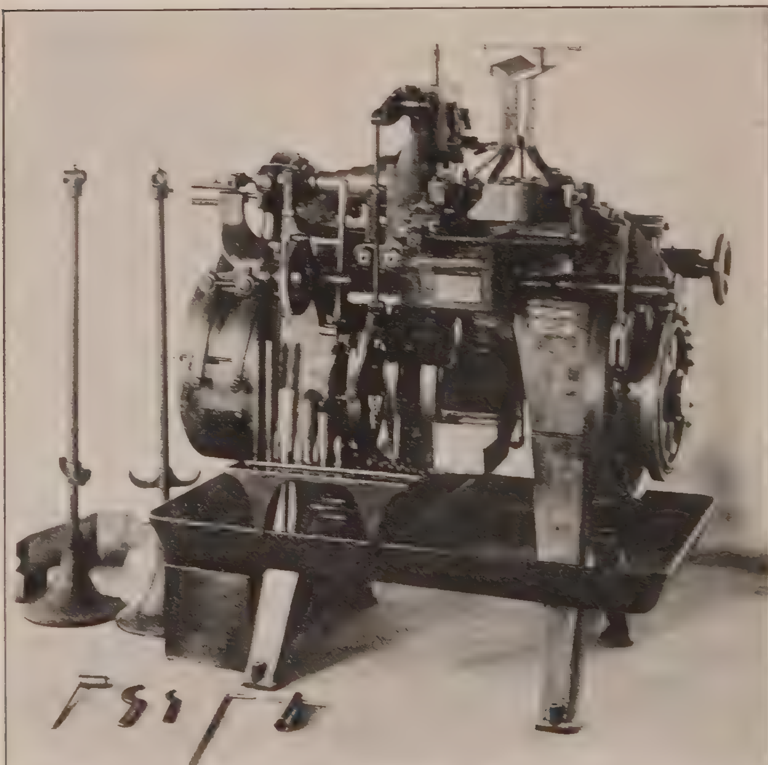

Fig. 17. The Davenport Automatic Assembling Machine for Assembling and Finish-Turning Lantern Pinions for Clocks.

combination of automatic screw machine, press and staff lathe. The staff is made from a wire or rod in the screw machine spindle, and the various collets are carried in magazines on the turret and pressed on to the staff in the proper location. They are then turned and faced in position so as to run true, the

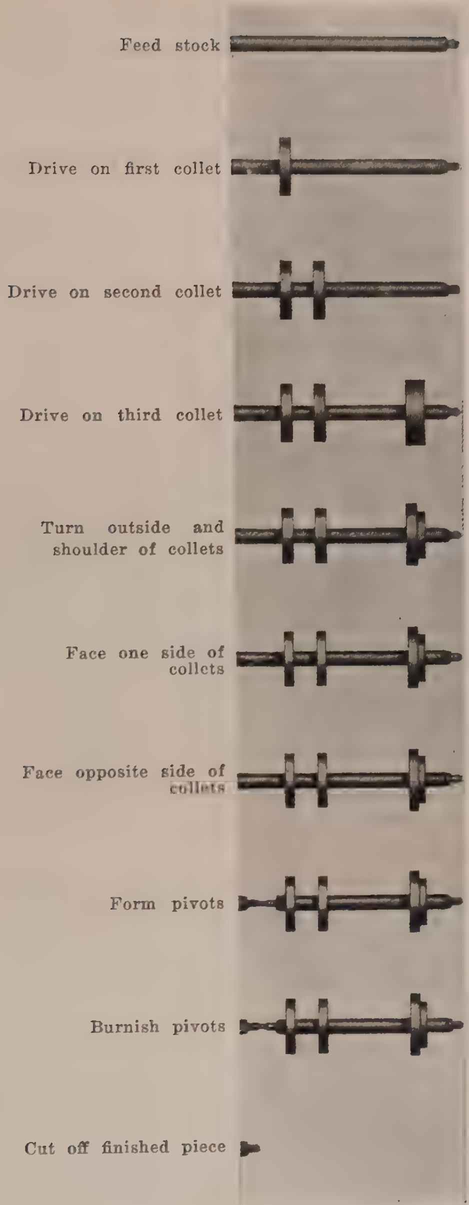

Fig. 18. Order of Operation for a Typical Lantern Pinion Job on the Machine Shown in Fig. 17.

pivots are formed and burnished and the completed pinion blank is cut off. This is a good example of the elaboration that is profitable in many kinds of work where continuous operation on the same piece can be obtained.

CONTEMPORARY PRACTICE IN AUTOMATIC MACHINERY.

Considering only the "automatic" in the limited sense in which it is used in the American machine shop, we have seen the following stages of development:

1. The hand-operated engine lathe.
2. The hand-operated turret lathe or screw machine.
3. The single-spindle automatic turret lathe or screw machine.
4. The multiple-spindle automatic.

Each of these types of machines is employed in the best modern practice. The respective fields in which they are most economically employed may be outlined about as follows:

The Engine Lathe, used for most special work in small quantities, for experimental work and tool making. In general, for non-repetition work. In some cases it is profitably employed for quantity manufacturing, using special tool holders, etc. See following section on "The Automatic and the Economies of Manufacture". Most large firms engaged in the manufacture of light- and medium-weight machinery get along (or should get along), with a surprisingly small proportion of engine lathes in their equipment.

Hand-Operated Turret Lathe and Screw Machine. These machines are a step in advance of the engine lathe, as they provide means for a multiplicity of tools permanently set and operating against positive stops. They are thus able to duplicate complicated cutting operations on a series of pieces with great accuracy. The smaller sizes, or "screw machines", have found their field of operation on bar work greatly reduced by such machines as the "Cleveland", shown in Fig. 19, which is particularly adapted to a quick setting-up on small jobs. The hand screw machine on small bar work is handicapped by the greater proportion of idle movements and handling time to cutting time. Continuous activity without rest periods would be required to

keep up with the automatic. But on work held in the chuck, particularly where turning operations are required, the automatic has not been developed to the point where it can compete on small work, and the small hand screw machine or turret lathe is consequently holding its own in this field. Its most serious competitor on work for which it is adapted is a machine of the type shown in Fig. 14.

In larger sizes of turret lathes the conditions are different. In the first place, the idle movements of the larger automatics can seldom be made any more rapidly than they can be made by hand, and the cuts are usually long enough so that the operator

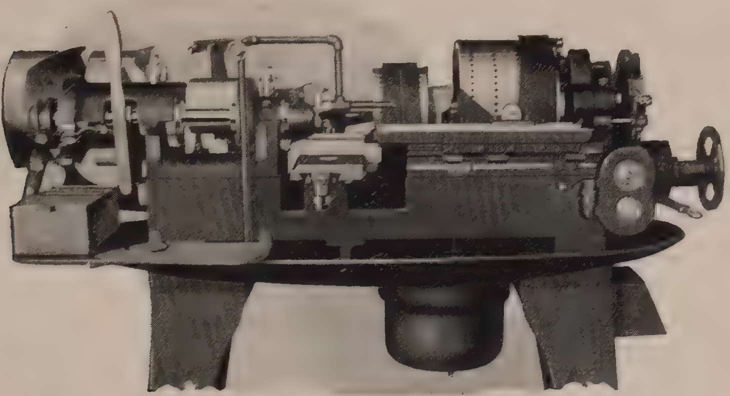

Fig. 19. The Cleveland Automatic Screw Machine.

has periods of rest, even when pushing the machine to its limit. The strong point of the hand turret lathe is intensive production. Constant supervision and the opportunity for instantaneous changes of feeds and speeds make it possible to keep these up to the highest pitch, while the automatic must work at a slower rate as insurance against trouble. The hand machine also costs less, as a usual thing, and does not require so large an expense in special tooling. Thus the hand-operated machine offers not only a greater output per machine, but a greater output for the capital invested as well. This includes floor space and other property changes, as well as the charge against the machine itself.

The automatic, on the other hand, often offers a reduction in labor cost that more than offsets the increase in overhead charges which it incurs. And there are sometimes conditions of the labor market such that the automatic is used even where the total cost of its product is known to be somewhat higher. It is undoubtedly true that there are many cases of hand turret lathes being used when automatics would be more economical, and there are certainly a great many cases when the reverse is true also. The merits of any particular case must be decided by the exercise of unusually good judgment; or, better, by a study of costs which takes the overhead charges into account as well as the labor cost. In this connection it may be noted that the manufacturing cost of high-grade machinery is usually made up of about one-third direct labor, one-third material, and the other third overhead charges of various kinds. Of these three items, that of material is not greatly affected by the style of machine used. In large work the hand machine tends to reduce the overhead charge, while the automatic machine tends to reduce the direct labor charge.

As previously stated, the multiple-spindle automatic screw machine is now firmly established, and capable designers are continually extending its field into more complicated and more accurate work. The large multiple-spindle automatic, like those shown in Figs. 12 and 13, is still a new venture, but the different machines of this type are being developed by skilled engineers, and the merits of the idea will have a thorough trial under the best possible conditions.

AUTOMATIC MACHINERY AND THE ECONOMICS OF MANUFACTURE.

If there is demand enough for an article to support large establishments for its manufacture, and if there are no patent or other restrictions to keep its manufacture in the hands of men of limited ability, the normal tendency is toward quantity manufacture in large establishments. The cheapening of production by using automatic machinery on large lots is an important factor in this tendency, although it is only one factor of several.

If the article of manufacture (such as an automobile, ma-

chine tool or agricultural machine) can be standardized, so that the design changes little from year to year, the advantages of large scale manufacture are still more apparent. Machines can be kept on one piece continuously day and night, if necessary, until worn out. Operators can be trained to great skill, not only in getting large output for the comparatively few pieces or operations in their repertoire, but in getting a high grade of

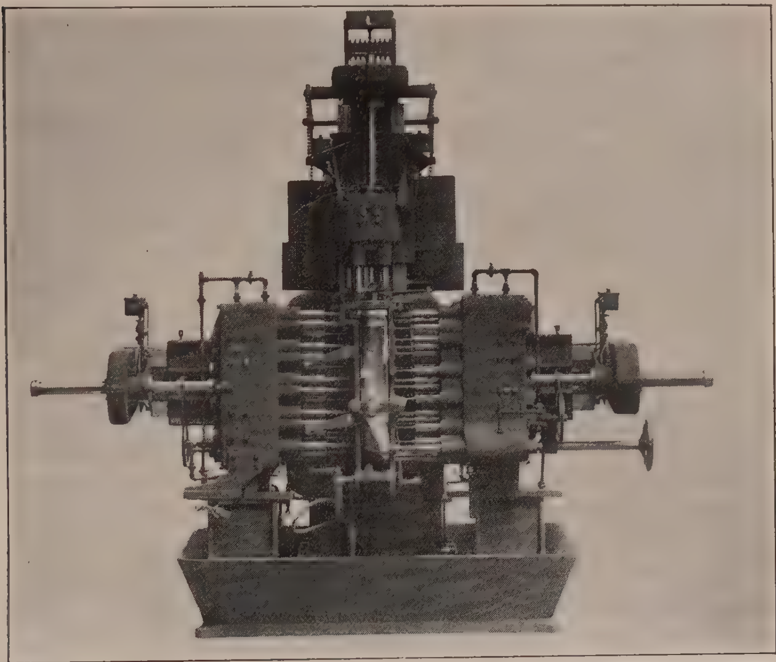

Fig. 20. A Typical Special Automatic Machine designed for Drilling a Particular Piece of Work; built by the Foote-Burt Co.

workmanship as well, where that is necessary. Special machines, each built for one operation only on a single piece of work, can be profitably used. Such a machine is that shown in Fig. 20, which is designed for drilling automatically and simultaneously 84 holes in a particular design of automobile transmission case.

It is obvious that such a manufacturing system has its disadvantages. The most obvious of these are the necessity for

keeping the product free from change so far as possible; and, also, the monotonous character of the work from the operator's standpoint. In answer to the first objection, it is, of course, obvious that no industry is fit for this large-scale, intensive manufacture until the product is fairly well standardized; or at least until the particular design selected for manufacture is such that it will suit a large percentage of possible customers. To increase the field of customers, such an establishment is in a position to offer attractive low prices for its standardized output, in place of the frequent novelties and special features offered by the smaller manufacturers.

There is also something to be said for such an establishment from the standpoint of the workman. An immense amount of ability, of the highest order, must go into its management; and its organization furnishes opportunities for many such men. On the other hand, for workmen of faithfulness and dexterity but small originality, it can and ought to furnish work at higher wages than they could obtain in any other employment. Many skilled workmen, as well, find these high wages a compensation for the monotony of continuous work on one piece.

It must not be understood that all large-scale production is carried on in the ideal way just suggested, but there is a measurable movement toward these conditions, and there is at least one American automobile manufacturer who has become world-famous in working out the plan.

There is one factor in large-scale production which, curiously enough, tends away from automatic machinery of the costly, complicated type. In quantity manufacture one of the lines of study that gives largest rewards is that of adapting the design of the product to the methods of manufacture. It is usually possible to thus greatly reduce the cost without reducing the desirability of the product in any way. It is, furthermore, possible by this means to do the work on much simpler machines in many cases. And the result of such study is often to lessen the machining and divide the operations up into simple, quickly performed units. These may be done very rapidly by trained operators with special tools on ordinary machines. This tendency is especially noticeable in such highly organized industries as the building of textile and agricultural machinery, where the drill

press and simplified forms of engine lathe are the most commonly used machines.

Industries large enough to be organized on the high production basis may thus be made practically free from the competition of smaller firms, if the product can be standardized. And this method of manufacture at the same time offers the opportunity of good wages to the mechanic, and low cost to the consumer. While these principles apply to all manufacturing countries, they are especially favorable to the United States. In competition with other nations, this country offers the great advantage of the largest initial home market, and is thus especially fitted to make the first application of quantity production to any given product.

In the development of quantity production, the automatic machine plays a large part, not only in the metal working field we have just been considering, but in practically all other lines of manufacture as well.

DISCUSSION

Mr. Burlingame.

Mr. Luther D. Burlingame,* Mem. Am. Soc. M. E., in opening the discussion stated that considerable discussion had taken place recently as to the relative values of automatic control and hand control. Mr. Flanders had pointed out the conditions making the use of automatic machines profitable.

The subject of indexing was a problem for the automatic. The use of the Geneva stop and the consequent slowing up on the speed at the moment of indexing had tended to make the indexing more accurate.

One disadvantage of the automatic was that the stock had to be of more uniform character than for hand control, but this has been overcome by the design of chucks which will handle sizes having some irregularities.

Separation of the work and chips is now automatically accomplished.

Means of changing the speed for hard spots in the castings or bars has been found.

The Warner and Swasey Co.'s exhibit at the Exposition shows semi-automatic control brought up to the standard of hand control. The Jones and Lamson Co. also brings this control up to the same standard, though neither the author nor Mr. Hartness, through modesty, brought out this point.

Automatic means have been devised in gear cutting for forming a locking device to cause all work to come in sequence, so that the work

* Industrial Supt., Brown & Sharpe Mfg. Co., Providence, R. I.

Mr. Burlingame. or material will not be injured by the stoppage of certain parts of the machine, while others continue to move.

An automatic device has been applied to screw machines so that the stock itself serves to drive the cutting devices in milling heads, and in making pinions, in index drilling, etc. The additional operations of slotting, drilling, etc., are arranged to be carried on simultaneously with the other operations, thus avoiding loss of time.

*The belt drive for feed, urged by Mr. Barth, is good in some instances, but in many cases they had found gear drive more satisfactory, as in the case where the load is very heavy.

His experience had been that it was best to have the feed independent of the speed.

The automatic cross-feed in the grinding machine is a new development. At first it was thought that feeding must be done by hand, at the judgment of the operator; however, automatic cross-feed has now become well established.

What is a special feature of today, five years hence may be considered as regular equipment. Thus, automatic control is constantly being applied to parts where it was formerly considered essential to have the control under the care of an operator using his best judgment in each particular case.

Mr. Rogers. **Mr. Fred E. Rogers,**† Assoc. Mem. Am. Soc. M. E. (by letter) expressed the opinion that practice, as developed in the use of the automatic screw machine, was extremely economical on small parts, the labor cost being reduced to a minimum, so that it was no wonder that the number and variety of automatic screw machines had increased amazingly. However, with the development of the machines into larger sizes, it had been found that the waste of stock, due to forming by cutting operations and converting a large part into chips, had become a serious matter. Hence, there has been a general realization that the common automatic machine tool may not always be strictly economical, when alternative means of manufacture are considered broadly.

The point he desired to make was that in the race to develop automatic machine tools, there has been the most activity displayed in developing bar machines which produce marvelously well, but with much waste of metal. The future requirements of manufacturing will be much more rigid than in the past in regard to quantity of materials used. Costly metal must be saved, which will operate against the unlimited expansion of the plain bar type of machine. Preliminary operations of forging will be required, which will make the handling of the work more difficult than before, but the economies resulting from the saving of metal, cutting time, tools, power and lubricants—to say nothing of the improvement in the product—will well pay.

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* See discussion by Mr. Barth of Mr. E. R. Norris' paper "Machine Shop Equipment, Methods, and Processes".

† Editor, Machinery, New York, N. Y.

There has been some development of practice in brass working, of casting the parts in "strings" and providing chucks and feeding tubes that handle these string castings the same as plain bars, with resulting saving of metal in the castings, reduction of machining time and improvement in the quality of product. Mr. Rogers.

The tendency all along the line of metal working practice, wherever the product is produced in large quantities, is to form it to shape by pressure rather than by the use of cutting tools. The lathe is essentially a cutting machine. It is the universal machine tool and one that will always be largely in demand, but when it comes to producing parts in lots of 100,000 or 1,000,000 it is clear that it is a costly machine to use as compared with presses.

The automatic machine tool, doubtless, will be required more and more to handle parts that have been cast, forged, drawn or otherwise shaped to save waste of material. These automatic machines will be more complicated and costly than existing machine tools, but they must come, because the demand for greater economies in manufacturing makes their development imperative.

The scrap pile of a screw machine department represents not only waste of metal, but waste of lubricating oil, unnecessary wear and tear of machines and cutting tools. If nine tenths of the forming operations were done by pressure, the remaining one tenth being reserved for finish by cutting operations, the scrap pile and the wear and tear of machines would be diminished, the life of the cutting tools increased and the quality of the product improved.

Paper No. 121

HIGH TEMPERATURE FLAMES IN METAL WORKING.

By

H. R. SWARTLEY, Jr.
Jersey City, N. J., U. S. A.

To survey properly the development of metal flame welding and cutting entails a consideration of the gases employed and the facilities provided by the manufacturers of such gases, or the materials from which they are made, to furnish an adequate supply. For "autogenous welding", which is the term applied to fusion of metal under the action of a blow-pipe flame, various forms of fuel gases have been employed, all of them, excepting hydrogen, being some form of gaseous hydrocarbon.

Some of these fuels owe their origin to reclamation of waste or by-products of petroleum industrials. In this class may be included the fuels, which, combined with oxygen, produce the flames known as oxy-benz, oxy-gas, Pintsch gas, blaugas, etc. The rapidly developing field of autogenous welding, doubtless, is responsible for the efforts of the manufacturers, and those interested in the promotion of these fuels, to develop to the highest economic degree the output of their works. The light of development, however, is focused most strongly upon acetylene—that excellent product of the electric furnace. The almost universal preference for this fuel gas, which, used in combination with oxygen, covers almost the entire field of autogenous welding, is based upon well-defined theoretical and working factors.

The two factors governing the degree of flame temperature produced by the combustion of a fuel gas in air or oxygen are the calorific value of the fuel gas and the nature of the products of combustion. If the products of combustion are of low specific heat, the flame produced by burning a fuel gas of high calorific value will produce a flame of high temperature;

but if the products of combustion are of high specific heat, the flame temperature is lowered proportionately. A consideration, therefore, of choice of fuels to be employed points to the selection of those containing the highest percentage of carbon with the minimum amount of combined hydrogen, for the reason that the products of combustion of any hydrocarbon are water vapor and carbon dioxide (CO_2). Water vapor, however, has a much higher specific heat than CO_2; hence, the temperature of the flame produced by the combustion of a fuel gas of large hydrogen content will be lower than that attained by burning a fuel of higher carbon content with a minimum of hydrogen.

Acetylene (C_2H_2), containing only about 7% of combined hydrogen, has a higher specific gravity and greater calorific value than any of the commonly employed fuel gases, and may be considered as the nearest possible approach to gaseous carbon. Other fuel gases may contain not only more combined hydrogen than acetylene, but an additional 5% to 50% of free hydrogen, which, burned to water vapor, will absorb more heat and still further lower the flame temperature.

Combustion of a fuel gas naturally reaches its highest point of efficiency when burned with pure oxygen. Inasmuch as the cost of oxygen is greater, volume for volume, than any of the fuel gases, its consumption naturally is increased for equivalent working performance by absorption of the additional heat units in the combustion of fuel gases of greater hydrogen content. It is, therefore, apparent that acetylene offers the greatest economic possibilities in best meeting the commercial requirements imposed in adapting autogenous welding to specific manufacturing operations.

The working requirements governing the selection of the fuel gas to be employed are ease of production of the gas, safety in its use, ease of application, and high quality of work produced. A prime consideration of autogenous welding, from the standpoint of manufacture, is that it shall produce welds of definite strength, the efficiency of which may be fairly guaranteed. At the inception of the process in Europe these requirements were not well defined, but as the variety of application and scope of the art attained greater proportions, they

became better outlined, with the result that the present status of autogenous welding shows practically universal selection of acetylene as the fuel gas which seems best to meet the governing factors. In metal cutting, the factor of the fuel employed becomes of less importance, the oxygen requirement being the principal consideration.

In consequence of the ever increasing carbide demand, that industry has received an impetus far beyond the degree to which it might have been carried by the output necessary for lighting, for which purpose it was originally established. Acetylene may be produced, under practically any condition of climate or temperature, in a generator of simple construction, in which the salient features conform to approved insurance requirements and the regulations governing operation. The development of a successful method of compressing acetylene, whereby large volumes may be transported under pressure in proportionately small bulk, has resulted in the establishment of "compressing stations" with facilities for supplying gas, in portable containers, to practically any part of the civilized world.

Inasmuch as all of the fuels employed require oxygen for their combustion, a glance at the rate of growth of production of this gas will afford a measurably full indication of the increased application of high-temperature flames in welding and cutting.

The development of autogenous welding and oxygen cutting and the rapidly increasing use of the process in England and Continental Europe resulted in the establishment, in manufacturing centres possessing the largest potential oxygen demand, of generating plants for producing the gas by fractional distillation of air. In Germany and Switzerland the oxygen supply, owing to low cost of hydro-electric power, was largely supplemented by the output from industrials dissociating water on a commercial scale. A ready market for the by-product (hydrogen) was found for dirigible balloon purposes, conversion of vegetable oils and animal fats into edible products, etc. Later, the electrolytic oxygen process, also, was introduced into England.

The introduction of the autogenous-welding and cutting

process in this country was attended by great difficulty in obtaining an adequate oxygen supply, although many purchasers of welding and cutting equipment installed apparatus for producing oxygen by chemical means—naturally, at a comparatively high cost. The concerns exploiting the process and embarking in the manufacture of the apparatus for carrying on the work found ready co-operation in the carbide industry, which has consistently increased production to meet the demand. The commercial oxygen supply was that afforded mainly by isolated water-dissociation plants, the hydrogen product of which was utilized in manufacturing purposes, and the oxygen allowed to escape to the atmosphere. Provision was made to store and compress the by-product, oxygen, into portable cylinders. This was the beginning of the commercial oxygen industry in the United States.(1)

With the completion of an air distillation plant on the Great Lakes(2) there was begun the first commercial production of oxygen in this country to meet the demand of the new industry, which, together with the inauguration of a system of distribution by portable cylinders, has increased to such an extent that the cylindrical metal containers for the transportation of oxygen are now familiar objects. The commercial oxygen business has grown by leaps and bounds until the total of the capital invested in the plants and appurtenances, together with the distributing facilities, is large enough to class the industry as a most important one in the list of manufacturing enterprises in this country.

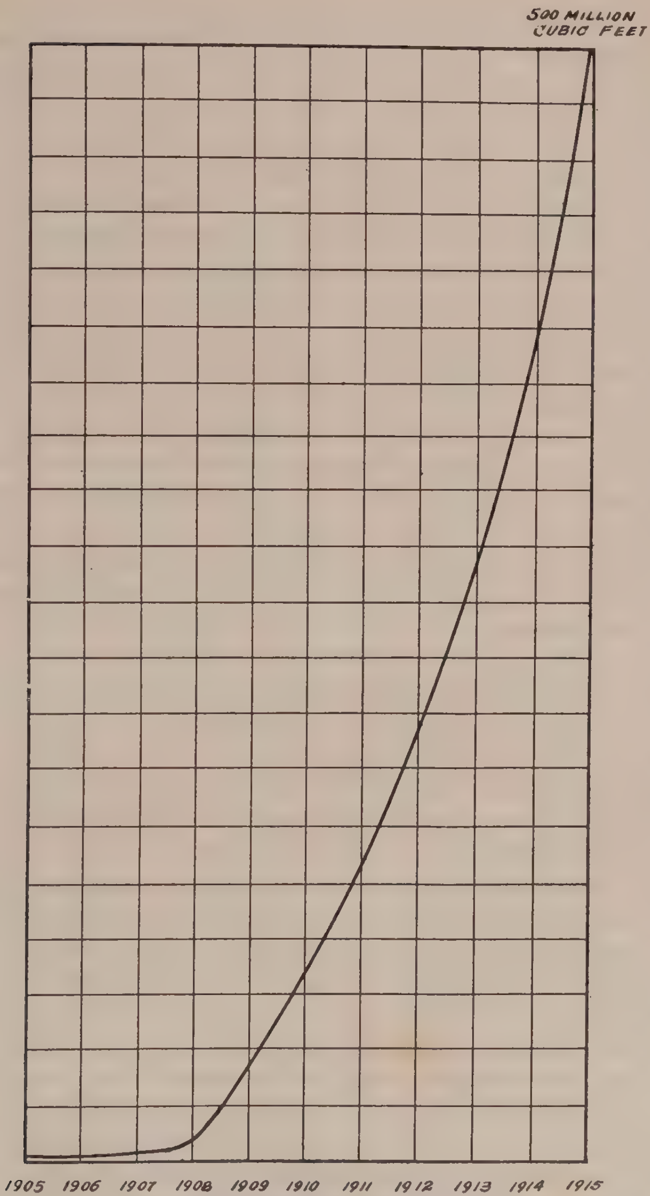
One company(2) claiming, with evident reason, to produce a greater amount of oxygen than any other in the world, has within the past three years established thirty-three oxygen-producing plants and distributing depots, located in manufacturing centres of the United States, and has under contemplation additional plants to meet the still rapidly increasing demand.

Advantage has been taken of low power cost in some sections of the country to install electrolytic oxygen-hydrogen producing equipment, in some cases hydro-electric power offering inducements which may render an installation profitable; and the application of autogenous welding to manufacturing has

resulted in the installation of electrolytic oxygen-generating equipment by some of the larger industrials. The world curve following may be considered fairly representative of the present volume of oxygen consumed by the welding and cutting industry. The curve is based on percentage of production, with increments for each year, and affords, therefore, a measure of the rate of growth and a means of deducing the importance to which this process has attained in a comparatively short time.

The European development of metal-welding processes may be considered as an extension of soldering or brazing operations, and, as such, generally limited to work on comparatively light sections. It is of interest to note that these limitations were, to a great extent, imposed by the almost universal employment of the low-pressure, or injector, type of oxy-acetylene blow-pipe, acetylene then being available only at slightly above atmospheric pressures. Experiments having shown that better results were obtained with acetylene delivered at the burner tip under independent and appreciable pressure, a type of torch designed to employ both acetylene and oxygen under pressure was brought to the United States in 1907,(1) and a generator providing acetylene under requisite pressure was produced. From that time, the development of the so-called high-pressure welding torch was rapid in this country, resulting in the extension of the new process to a much wider field than had before been possible.

A theoretical consideration of the means whereby the high temperature flame, approximately 6000° F., is produced by the combustion of acetylene in oxygen, shows that 2½ volumes of oxygen are required to burn one volume of acetylene (C_2H_2) completely to its products of combustion,(3) which are carbon dioxide (CO_2) and steam. Acetylene being an endothermic gas, dissociation into its two constituents, carbon and hydrogen, occurs on issue of the mixture from the blow pipe. The supply of oxygen burns the carbon to CO, producing the characteristic white flame at the nozzle. In order to form CO, equal volumes of acetylene and oxygen are required, accompanied by a phase of combustion in which CO burns to CO_2 and the hydrogen later combines with oxygen to form steam.



World Curve of Oxygen Consumption.

If it were possible to supply a perfect mixture (equal volumes) of acetylene and oxygen at the nozzle of the blow pipe, the oxygen required to burn CO to CO_2, and the hydrogen to steam, might be abstracted from the air. In practice, however, some of the oxygen required to burn CO to CO_2 must necessarily come from the blow-pipe supply, so that the best torches manufactured today operate successfully with a mixture of 1.1 volume of oxygen to 1 volume of acetylene. The hydrogen evolved, combined with atmospheric oxygen after it has passed from the high temperature zone of the welding flame, surrounds the molten metal and prevents oxidation, at the same time protecting the heated inner cone from loss of heat.

Acetylene supply under low pressure necessitates the employment of a blow-pipe of the true injector type, in which excess oxygen pressure must be supplied in order to deliver the mixture of gases to the nozzle at proper pressures. The limitations of this form of construction afford a less perfect mixture of gases than in the type of welding torch utilizing acetylene and oxygen under independent pressure, and the oxygen consumption is undoubtedly higher than in the latter form of construction.(4) An imperfect mixture of gases results in unsteadiness and instability of the flame, which, together with pre-ignition of the gases while in a mixed condition, due to preheating of the blow-pipe nozzle through radiation from the work carried on, produces results less favorable for the continuous operations of manufacture and requirements of steady operation.

The strength of the joint produced by autogenous welding has been a fruitful source of discussion in the application of the process, and many contentions have been advanced as to the necessity of welds of highest tensile strength. It was early found that 100% welds, or, in other words, those having a breaking strength equivalent to that of the metal itself, could be produced, but the sacrifice of elongation and reduction of area materially lessened the apparent value of such welds. Present practice is directed toward securing a weld of good tensile strength, as compared with the strength of the plate, with high ductility, since, thereby, the service conditions are better fulfilled.(5) The growth in understanding of such re-

quirements has resulted in the production of methods, which, combined with proper apparatus, may uniformly produce these results.

European practice covers the use of the low-pressure acetylene generator and injector type of blow-pipe almost exclusively, the independent-pressure type of torch having shown little development, despite its well known economy of operation. This may reasonably be accounted for by the low prices obtained for the welding and cutting equipment in general use not warranting the expenditures requisite for further development.

The introduction of the process, however, in this country(7) was accompanied by the development of the medium-pressure positive-mixture torch, utilizing both gases under independent pressure, assuring, thereby, stability and quality of the flame, theretofore not produced by the injector form of construction. The applications of the process, in consequence, assumed a radically different aspect than that revealed by the country of its origin, with the result that there has been, and is being, performed most remarkable work in the welding and joining of heavy sections in reclamation and repairing, which, in comparison with the progress attained abroad in similar work, shows advanced practice.

The field in which this country excels that covered by present practice in the countries where the process originated has been developed almost entirely by the pioneer effort and large expenditure of those embarking in an enterprise the limitations of which were unknown. Many discouraging failures and costly experiments mark the way to the present undisputable success of the process and its application to modern manufacture.

The early application of the art in this country was generally confined to the establishment of welding repair shops, in which the character of work comprised the reclaiming of broken or defective parts. Manufacturing establishments first adopting the process considered it principally in the light of repair, with only possible applications to the manufacture of their products. It may be said that the quality of work done was in proportion to the degree of knowledge of the limitations of the art then existing. In common with any process

capable of elaboration to a similar extent, many attempts were made to perform operations, the successful carrying out of which was beyond the capabilities of the organization and the facilities existing, the results being often to discredit the real value of the process if applied under proper auspices.

A great stimulus to development of oxy-acetylene welding and cutting has been the wide dissemination of knowledge, both theoretical and practical, gained through ceaseless experiment and testing of results produced, by makers of equipment for generating acetylene and oxygen and of welding and cutting apparatus.

The requirements for the production of successful metal welding, as a substitute for existing methods, has led to exhaustive research, along metallurgical lines, to develop materials and fluxes which, used in combination with the high temperature flames available, would best produce the character of work demanded. The establishment of laboratories by such manufacturers made it possible to obtain proper materials for carrying out desired operations on practically all known metals utilized in manufacture, together with advice and instruction for successfully applying the process.

Those concerns engaged in the manufacture of autogenous-welding apparatus have best succeeded whose foresight and initiative early recognized the necessity of themselves bearing the expense of making demonstrations, often unsuccessful, providing instruction to users, and continuously developing and improving their apparatus, the combined cost of which, many times, formed the largest item of expense in carrying on their business.

The trend of development in welding torches shows a progressive adoption by the rapidly increasing number of manufacturers in this country, of a construction which admits the gases under independent pressures. A review of exceptional performances, particularly of welding of heavy sections, covers a period coincident with the inception and exploitation of the medium-pressure form of torch with the accompanying successful acetylene generator producing that gas under pressure.

It is a prime requisite of operations carried out in the constantly multiplying instances of heavy metal-section welding,

the description of which forms so appreciable a portion of the subject matter of our technical press, that the work be carried on continuously, on account of possible failure due to shrinkage strains and similar causes.

For operations of this character it will be noted that the medium-pressure positive-mixture form of blow-pipe is almost invariably employed, due to its ability to withstand the high pre-heat temperatures to which it is subjected during the performance of the work and to the better combustion obtained.

The increasing publicity afforded the use of high-temperature flames in the technical literature of this country and abroad has furnished means of comparison of the variety and scope of work done, with the result that it is not uncommon for foreign manufacturers to import American-made equipment for carrying out the operations in heavy metal sections.

As illustrating this condition, positive statements have been made in letters to an American manufacturer,(1) in at least two instances, which are worthy of consideration: The chief engineer of one of the largest German steamship lines stated, after investigation, that in this country work was being done with oxy-acetylene process that, to his knowledge, had not been attempted in his country; and an authority in England, who is editing one of the technical publications and is also an instructor in the Northern Polytechnic Institute, as well as translator of one of the most widely circulated French text books on autogenous welding, states that "we are a good distance behind your country in making progress".

The discovery that a jet of oxygen directed upon a previously heated steel or wrought-iron section was capable of burning the metal to iron oxide, and furnishing, thereby, a most convenient and effective means of cutting sections up to 30″ in thickness, marked an epoch in the development of the world's metal-working industries.

Here, too, long and patient experimenting was necessary to evolve the form of cutting-torch construction that would satisfy working conditions and in the determining of principles covering its operation.(8) It was early appreciated that, in order for oxygen metal-cutting apparatus to attain its recognized standard in metal-working fields, there were involved the factors

of low-cost gas supply and minimum consumption of gases per square inch of metal oxidized.

With the establishment of oxygen-generating stations and distributing service, the first of these requirements has been met; for the second, the time and energy of apparatus manufacturers have been devoted to making it possible to substitute the oxygen cutting torch in a rapidly increasing number of instances, where, formerly, only most laborious and expensive methods were possible.

Recent notable instances are: (9)

Armor-plate, 16″ thick, cut at the rate of four lineal inches per minute—the oxidation of the steel being effected at the rate of more than 1 square inch per second.

Cutting gun port in armor-plate, 18″ thick. Time required 50 minutes. Operation ordinarily requiring four weeks of drilling with subsequent two-weeks' machining time.

Fifty-two lineal feet of gun-turret top, of armor-plate 5 inches thick, was cut at the rate of 8 lineal inches per minute, after which 48 lineal feet of the edge of the plate was beveled at 15°, with the cutting torch; the entire cutting operation requiring 2 hours 10½ minutes. It was estimated that by former methods of drilling and then beveling on a large lathe, four weeks' time would be required and a cost entailed of about $2,000. The cost of gases for cutting by the method employed was $54.38.

A 7500-ton cast-steel cylinder, representing a pouring of 140,000 lbs., had five risers to be removed, one being 36 inches in diameter and weighing about 15 tons. The apparent difficulty of removing the risers was quickly overcome with the cutting torch, the 36-in. riser being cut in 1¼ hours.

These cutting operations were accomplished with mechanically-guided torches employing oxygen with hydrogen as the fuel gas.

The wrecking of steel structures,[10] in which line of industry the application of metal cutting by oxygen has become so common, is a familiar sight in every town and city in the United States. As an economic factor in the removal of burned or wrecked structures which normally possess high earning capacities, the oxy-acetylene cutting torch, applied by concerns spe-

cializing in that class of work, has effected incalculable savings in clearing the way for replacement of the destroyed buildings.(11)

Railways include the metal-cutting torch, with a supply of stored gases, as an integral part of their wrecking equipment. Fire departments, through the medium of apparatus capable of being handled by one man, may remove barriers to the escape of individuals in burning buildings in a small proportion of the time so often found inadequate for the saving of lives.

Originally conceived of as a tool best adapted for shop conditions, the autogenous welding and cutting process has attained to proportions in field work the size of scope of which make prophecy regarding the future indeed difficult.

Hydro-electric pipe lines showing service defects, for the repair of which ordinary methods were inadequate, in view of the pressure carried, have been restored to normal condition by autogenous welding carried out under most unfavorable conditions of location and climate. In some cases, after such lines have shown their full measure of service, to which the use of the autogenous welding process has been a contributing factor, they have, in turn, been removed by the cutting torch. Instances of cutting operations of this character running to miles in length are not uncommon.(12)

It is customary to speak of welding in terms of lineal feet. Within the past year there was completed probably the largest operation in autogenous welding ever attempted, comprising the joining of the roof sections of a metal flue, the aggregate amount of welding totaling ten miles.(13)

As indicating the wide range of application of the process, manufacturers of jewelry employ autogenous welding for the joining of precious metals requiring for their successful manipulation the production of high-temperature flames equalling the size of a needle point, under most exact adjustment and control.

Autogenously-welded tube and pipe sections have formed important parts of foreign-constructed machinery. Welded sheet-metal formations of exceedingly intricate character for many years puzzled the minds of American manufacturers, as to the method of production, until the application of autogenous welding provided a solution of the problem of duplication.

A review of the attempts made by manufacturers in this country to duplicate foreign-made products shows that they were working under manifold handicaps, some of which were inability to obtain mechanics trained in the use of the process—with the added disadvantage that the only labor obtainable demanded a much higher wage than the foreign artisan—and the generally uninformed condition existing in the minds of possible purchasers of such products as might be developed regarding any form of construction embodying autogenous welding.

Some few attempts were made to overcome the labor handicap by importing foreign-made machines for the manufacture of pipe, which proved unsuccessful owing to the construction and methods employed being totally unsuited for American conditions. It is interesting to note that there are now under construction in this country industrial establishments capable of producing autogenously-welded tubing, by mechanical operation, in quantities sufficient to compete with modern tube mills employing the lap-welding methods([14]) and with seamless drawn tubing.

The enterprises that have sprung up in many sections of the country for the production of cylindrical metal packages are in response to the economic pressure brought to bear by the fast decreasing supply of timber suitable for manufacturing of the wooden package formerly employed. The riveted metal container imperfectly meets the conditions of transportation in eliminating leakage, which factor, it has been stated by large oil producers, frequently constitutes 1% of their total oil production.

At present, hand-welding methods constitute almost universal practice in the metal-container industry,([15]) but the development within the past two years and the introduction by various manufacturers of American-designed and -built mechanically-operated welding machinery([16]) offer possibilities in the production of these articles in quantities heretofore unattainable, and at a proportionately lowered manufacturing cost.

The repair of steam boilers showing service failures has been a fruitful source of discussion since the inception of autogenous welding in this country. Practically from the begin-

ning, national, state and local regulations have prescribed the amount and character of work that may be done.

Doubtless the greatest handicap to more general expansion of the process, in this industry, has been the failure to adopt methods of licensing apparatus, the concerns using same, and the operators, the necessity of which has been fully appreciated in Europe, where the employment of a mechanic of this class is conditional upon his holding a certificate of fitness. Considerable effort in favor of such measures has been put forth by those interested, with the possibility of ultimate success.([6])

Autogenous welding now forms an integral part of the manufacture of many types of stationary and locomotive boilers, the extent of the application being largely that developed by individual manufacturers. One of the most successful types of high-efficiency locomotive boilers owes its inception and development largely to autogenous welding, without which it would have been admittedly a vision of the designer, due to the insuperable obstacles to its production by ordinary methods.([17])

The most valuable adjunct to locomotive boilers, the superheater, may be said to owe its development and rapidly increasing application to the superior methods afforded by the welding blow-pipe of joining the sections.

The introduction of the steel railway car entailed many new problems in joining metal sections, with the ever present condition of light weight as a governing factor, which, unless overcome, would have proven a handicap of more than passing value in favor of the wood car. The stimulus afforded manufacturers of this class of equipment has resulted in metal formations and constructions that may be classed as revolutionary, compared with the practice even of five years ago.([18])

That the substitution of autogenous-welding methods for those formerly employed in the manufacture of metal products in which the qualities of finish and appearance are accompanied by requirements of strength is commanding attention to a distinctive degree, is evidenced by the publicity given to the adoption of such improved processes in the advertising and sales literature of the manufacturers of steel office, bank and hospital furniture, metal sash, doors and trim.([19])

In the effort to improve upon methods regarded as standard in various industries, those worked out in the development of high-pressure gas, for illuminating and other purposes, are distinctive to a marked degree. Many new distribution problems were entailed, notably in the construction of pipe joints and connections that would be tight against the increased pressure, and, at the same time, be capable of production at moderate cost.[20]

It is interesting to note that all pressure gas mains in the Panama-Pacific International Exposition grounds were joined by autogenous welding, and that the company supplying the commodity, which, incidentally, was the first company to introduce high-pressure gas and developed it to a greater degree than others, was a pioneer in such application of the process. There is laid, altogether, in the Exposition grounds over 100,000 lineal feet of pipe varying from 4 in. to 16 in. diameter, joined entirely by oxy-acetylene welding.[21]

In general steel and iron-plate working lines, the manufacture of air receivers and tanks, the production of heavy piping, special bends and fittings, coils, pans, steel boats, vaults and casks have introduced economies and perfected the construction by welding; and have done so in a way that augurs most encouragingly for the future.

The truly amazing economies and advances in the rate of production of the modern motor-car have been assisted, to an acknowledged degree, by the continuous study and application of autogenous welding and cutting methods, notably in the welding of steel and aluminum bodies.[15]

Over earth and under sea, the modern dirigible, airship and submarine owe a substantial measure of their development progress to highly specialized applications of this process.

The ship-building industry, notable as a pioneer in the introduction of autogenous welding and cutting apparatus in this country, has made large installations of gas-generating and metal-welding and cutting equipment.

It is significant to note that the U. S. Government may be considered as responsible, to a degree, for the working out of numberless applications, due to the stimulus provided by requiring certain operations to be carried out exclusively by autoge-

nous-welding and cutting methods.[22] All government navy yards have installations of the most complete equipment, and incorporate in their manufacturing regulations advanced labor and cost saving methods. One of the largest installations of oxy-acetylene apparatus was made by the Government at the Panama Canal in 1910 and has continuously been of inestimable value for keeping other equipment in commission by effective repairs.

The future of high-temperature flames, in this country, may be considered as depending upon the variety and scope of its application to manufacturing purposes. The efforts of constructors and designers are directed toward the production of forms suitable for autogenous-welding and cutting operations in substitution for present methods. With the prospect for development offered by the application of American methods, there is every reason to expect the development of the future to be limited only by the consumers' demands of the manufactured products.

There are now on the market special machines for gas-welding and cutting operations capable of rapid and uniform production, the actual performance of the work being reduced to a matter of machine control.[23]

The cutting of metal sections by the oxygen jet, guided and controlled by mechanical means, has resulted in the production of material to size and shape, with a rate of speed and cost reduction unapproachable by other methods.

The oxy-hydrogen cutting jet employed on the heavier sections presents exclusive advantages for operation on surfaces coated with scale or oxide.

While lacking, as yet, the instruction facilities afforded in Europe through schools and the large amount of technical literature available for individuals desiring to enter the profession of autogenous welding and cutting, we show continuous improvement, which, it is hoped, will finally assume a concrete form whereby these handicaps may be overcome.

It is considered that instruction facilities such as afforded through the medium of the English and Continental welding schools, which now form a part of every industrial and educational centre, would insure a greater growth, in view of there

being few institutions of that character here, and those of much less comprehensive scope. The purchase of autogenous-welding and cutting equipment by many institutions of technical education in this country, and the incorporation in their curricula of instruction in the art, may be considered a constructive effort toward more general diffusion of the theoretical knowledge now considered a requisite to extension and development of the process along advanced lines of manufacture.

An increasing proportion of the technical press is devoted to autogenous welding and cutting operations. which operations now form a considerable proportion of the developments recorded in such mediums.

In consideration of the high efficiency of American-made apparatus, and that there is now available a plentiful supply of gases, with a rapidly increasing amount of labor skilled in the work, future development should be measured only by the activities of those manufacturers whose business acumen leads them to adopt only the progressive things.

THERMIT AND ITS APPLICATIONS.

While not produced by the combustion of gases, the Thermit process, as applied to all welding except pipe welding, is essentially an autogenous process, in that the parts to be welded together are united by fusing liquid metal between them.

The high temperature necessary is produced by entirely different methods. In oxy-acetylene, or other gas welding, the fusion of the metals at the point of juncture is effected by the temperature of the blow-pipe flame, metal being added homogeneously from a suitable welding rod as required.

The Thermit process supplies its own heat and its own liquid metal, the latter being evolved in large quantities, the process being particularly applicable to heavy welding of steel sections.

The evolution of this process was due to the efforts expended by Dr. Hans Goldschmidt in attempting to produce for Krupp pure metals for alloying steel. In carrying out the prior-known reaction produced by heating a mixture of the oxide of the desired metal and aluminum in a finely divided

state, he discovered that by proper control of the temperature applied, the reaction would precipitate the metal in a pure form, leaving the aluminum oxide, or slag, floating on the surface.

This being the first successful application, in a commercial way, of the chemically reactive qualities of aluminum in combination with metal oxides, a series of experiments were inaugurated, resulting in production of many more metals and alloys. It was found that the reaction between aluminum and iron oxide produced a very pure low-carbon steel, and that the heat was extremely high, which led to the evolution and application throughout the world of what is termed the Thermit process.

The discovery may, therefore, be termed a by-product of the metallurgical laboratory, and, as such, assumes its place with so many of the commercial processes and methods with which the researches of science have endowed the manufacturer.

The temperature produced by the combustion of iron oxide and finely divided aluminum, while never exactly measured, may be stated to approximate 5000° F. [24]. In application, the production of a highly heated liquid steel at this temperature lends itself readily to operations permitting the flow of molten metal around the section to be united, amalgamating with them so that the whole will cool down to form a single homogeneous mass.

The successful application, in a commercial way, of the Thermit process has opened up a method of joining steel sections, either cast or wrought, the size of which is limited only by the practicability of carrying out the necessary operations prior to the actual performance of the work. As in the development of the gas-welding and cutting industry, similar ground was covered by those responsible for the introduction of the Thermit, whereby the burden of demonstration and proof of the value of the process were borne by the promoters.[25]

The introduction of the process into steam-railway work was a factor of prime importance in disseminating knowledge pertaining to the variety and scope of the applications possible to be made under the proper auspices. The repair of locomotive frames which have failed in service entails expenditures of time and money to take down and replace the equipment having no direct bearing upon the work necessary to be

done. Applications of the Thermit process to such work frequently necessitate no stripping of the engine, it being necessary to provide sufficient clearance about the broken sections for erection of the mold and crucible, together with application of the pre-heating means. The process may be applied to the welding of broken drive-wheel spokes, side rods, connecting rods, rocker shafts, cross-head guides and similar articles of the kind whose service requirements are of such character as to incur failure.

The economy of the process in certain locomotive repair work has led to its adoption by practically all of the railroads in the United States, Canada and Mexico, there being four hundred and fifty shops in North America employing the process to a greater or less extent.

In the shipyard, the welding of broken stern posts, stern frames, rudder frames and propeller studs of steamships is accomplished. From an economic standpoint, the savings incurred may be greater than attain in the railway shop, owing to the fact that dry dockage is exceedingly costly and that the saving of every day in the completion of repairs may mean hundreds and even thousands of dollars. Vessels undergoing repairs which would formerly be classified as of a very serious nature may not be detained more than 48 hours in the dry dock.

Several of the United States navy yards are employing the process, and in the building of the Panama Canal large quantities of Thermit were employed for welding and reclaiming broken parts of dredges, dipper buckets, locomotives, rock crushers, and in other operations.

In many cases, the applications of Thermit and gas-welding methods overlap to a degree dependent upon the experience of those responsible for results and the facilities attendant upon carrying out the work, and the factor of size of the metal sections to be joined many times determines the selection of the process to be employed.

Around the steel plant, the repair of large rolls and pinions by the Thermit process assumes considerable importance. Methods have been devised whereby such broken parts may be rebuilt by adding new metal to the old by an adaptation of well-known foundry methods assisted by the heat of reaction of the Ther-

mit process. When it is considered that the weight of such parts repaired may run from 15 to 17 tons, the reclaiming of them and their replacement in service assumes a most important factor in the modern requirement of continuous production.

Butt welding of pipes, eliminating thereby screwed and flanged joints and connections, presents a field of operation for Thermit which is both interesting and novel. As applied, the heat produced by the reactionary process does not, in itself, unite the sections, but is employed to raise them to a welding temperature, while the joint is made by mechanical pressure.

The electrification of street railways, involving the return of current to the power house through the rails, has entailed problems of maintaining conductivity of the return conductor upon which a large amount of development has been applied in the effort to meet the ideal condition, which is that of 100% conductivity. One of the principal developments of Thermit is that of joining the rail ends to form a solid mechanical joint, thereby eliminating the wear and tear on rolling stock due to open rail ends and the accompanying shortening of the life of the rail. The low electrical resistance of the Thermit joint insures maximum power saving due to high conductivity of the return circuit, and, at the same time, tends to keep down electrolysis of gas and water conductors made of metal.

Foundries and steel works utilize the high-temperature reaction afforded by Thermit to revive dull iron in the ladle and to keep risers of castings in a liquid condition, eliminating, to a large extent, the presence of slag and other impurities in the section adjacent.

As time goes on, probably many more applications will be discovered for the process, which is now only in its infancy. The work of scientific and technical investigators, which is now becoming such a large part of modern manufacturing, may be confidently expected to enlarge the scope of applications of the energy so quickly created by this combination of simple elements.

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DISCUSSION

Mr. W. A. Doble,* Mem. Am. Soc. M. E., stated, in lieu of discussion, that the paper dealt with two processes, but did not bring out the electrical process. In the case of hydro-electric work, the electrical process was more practical, as the electricity is available and it is much quicker. Mr. Doble.

He stated that they had made a repair on a 42-inch pipe line by oxy-acetylene welding, but it could have been done cheaper by electric welding.

One process uses the metal electrode, the electrode furnishing the metal for the weld. The other process is to use carbon electrodes, heating the metal and proceeding in a way similar to the method used in the oxy-acetylene process.

They had had a large Y, 42 inches to 30 inches, weighing 9000 pounds, of open-hearth steel, split in the Y and opened 3/16 of an inch. The Y was under 900-ft. head, and had been in service for six years, when it let go, being clearly a case of fatigue. It would have taken several months' time to replace it and have entailed the shut down of a plant

* Chief Engr., Pelton Water Wheel Co., San Francisco, Calif.

Mr. Doble. earning $400 per day. The man in charge of the repair left San Francisco Thursday night on a trip to the mountains. By Friday night the repair was completed and the Y has been in service eight months at the present time.

Electric welding is used very extensively to repair steel castings, chipping-out sand spots and repairing with the steel electrodes. It does not pay on cast iron.

It is also used in welding castings together, making simpler castings possible, and in some cases, where castings are subject to internal stresses, they are deliberately cracked apart and subsequently welded together, thus eliminating the internal or shrinkage stresses. He instanced the making of 20,000-pound Y castings by this method.

Paper No. 122

THE INTERNAL COMBUSTION ENGINE OF THE YEAR 1915. THE GAS POWER SYSTEM. A SURVEY OF ITS STATUS.

By

Professor CHARLES EDWARD LUCKE
Coumbia University
New York, N. Y., U. S. A.

The year 1915 closes a period of about forty years of development of a system for producing power from fuel by means fundamentally different from that inaugurated by James Watt, just about ninety years earlier, and until then universally used. Preceding this forty year period there can be noted a series of isolated inspirations out of which ultimately crystallized the internal combustion engine. Within the forty year period there is a well marked series of periods, each of about ten years and each marked by some big step in advance, similar to the preceding ninety year period of isolated steam engine development. It took thirty years to produce a Fulton, capable of suitably modifying Watt's steam engine to drive a boat and twenty years more before a Stephenson found a way to again modify the same engine to locomotive form, adapted to train haulage on rails. Now, at the end of its period of forty years of growth, the internal combustion engine stands in a position fairly commensurate with that occupied by the steam engine when the competition started. The rate of development has been about two and a half times as fast for the internal combustion as for the steam engine. The time elapsed between the big steps is almost exactly in the same relation, averaging between twenty and thirty years for the steam and almost exactly ten years for the internal combustion engine.

As the Englishman, Watt, demonstrated the commercial feasibility of generating power by steam, so did the German, Otto, demonstrate that the internal explosive combustion of a

mixture of gaseous fuel and air after compression could accomplish the same result, and internal combustion engines using gaseous fuel from the illuminating gas main came into commercial use at once. It took exactly ten years to divorce the internal combustion engine from the gas pipe, make it self-contained and able to travel about, and, therefore, a factor in transportation, by adapting it to the use of liquid fuel. This was accomplished about 1886, when Priestman, in England, showed how to operate with heavy distillate like kerosene, and Daimler, in Germany, developed the present carburetion system of treating light distillate like gasoline, and built some motor cycles, automobiles and boats.

Five years more and Dowson, in England, with his steam boiler fed pressure gas producer plant pointed the way to the adaptation of solid fuel. This power gas producer made but little progress, till five years later and at the end of another decade after Daimler and Priestman, Bernier, in France, demonstrated commercially the gasification of coal in small producers for internal combustion engines, without a steam boiler auxiliary. This completed the divorce of the new engine from the mains of the illuminating gas system of cities where it started its development, and for it all classes of fuels became available. Simultaneously Diesel, in Germany, established the injection system of handling heavy liquid fuels and commercialized the twenty-year old Brayton plan of non-explosive internal combustion in the most efficient engine the world has known. The economic range of use of oil fuel was thus extended to places where its excess cost over coal had previously excluded it. This was a busy time, and to these two a third step forward must be noted,—the successful operation by Thwaite of small engines on blast furnace gas in Glasgow, which, doubling the power production from this source over the then standard steam engines, proved the blast furnace to be as useful a source of energy as the water-fall, and one far cheaper to tap. This was the immediate stimulus for the building of large engines, first successfully accomplished a few years later by the Cockerills, in Belgium.

By the year 1900, almost twenty-five years after the Otto demonstration that internal combustion engines were com-

mercial, they had been adapted to both solid and liquid fuels, had been built in sizes ranging from a fraction of one to over a thousand horsepower, the large ones both single and double acting, and they had been applied to a wide variety of service, transportation by small boats, and road vehicles, and driving all sorts of stationary machinery, including electric generators. Much of this service was imperfectly performed and some desirable things could not be done at all or were done at excessive cost. The motor cars frequently broke down, cylinders of large engines cracked or wore out too quickly, ignition systems would fail and engines stop from this or from a multitude of other causes, some functional and others structural; cylinders became foul with carbon, interior parts overheated and pre-ignitions or back fires followed; good speed regulation was rare; costs of engines were high; most were poorly made and worse in design, reliability was bad except in some small sizes and styles; gas producers made bad gas as often as good, but rarely of constant quality and then only from selected sizes and quality of anthracite coke and charcoal; vaporizers of oil engines operated too hot or too cold or injectors became foul and oil engines worked badly. This was a period of great trouble for all, one of considerable financial loss to builders, and of constant complaint from purchasers, and yet the effort did not lessen. Through all this trouble, there was one strong, compelling fact that kept up hope,—all internal combustion engines were highly efficient thermally and therefore very economical of fuel, when they did run, and it mattered but little what sort of fuel they used or what their size; all were much more efficient than steam, especially so in small sizes, and this economy with the small weight per horsepower of the gasoline class was so unparalleled that development proceeded, in spite of discouraging mistakes, at an ever increasing rate, but along new lines.

Here began the fifteen year period of close study of performance, design, construction and adaptation to service, that brings the story to the present day for the internal combustion engine. This is the period of design that in any art always succeeds the earlier period of invention. The main lines of the scheme are laid down and generally accepted. Minute study

of each individual element of function or structure is undertaken by both designer and general scientific investigator and where formerly one engine differed from another fundamentally in plan, as did Brayton's from Otto's, now engines begin to differ in igniters, arrangements of cylinders and in number of cylinders and cranks, in mixing, proportioning and control valves and gear, all adhering otherwise to one general plan or system. Invention does not, however, stop, but is rather accelerated; but it no longer dominates, rational design replacing and absorbing it. For these last fifteen years the changes in the internal combustion engine and its auxiliaries have been more or less similar to those in the steam engine and its auxiliaries that are associated with the names of Corliss, Woolf, Porter, Willans, and Stumpf, dealing with details of construction that affect economy, special utility, first cost or upkeep of engines and with a similar group related to boilers, injectors, safety valves, damper regulators, superheaters, feed water heaters and economizers, condensers, feed, circulating, wet and dry vacuum pumps. Paralleling this in the internal combustion engine field there is a long series of names associated with an increasing list of special forms of parts for each individual function, dealing with ignition systems, spark plugs, batteries, generators, magnetos, distributors, governors, mixing valves, gas pressure regulators, water coolers, heaters and circulators, carburetors, heavy oil vaporizers, and injectors, starting valves and gear, silencers, and mufflers, piston rods, packing, lubricating systems and appliances; gas producer coal feeds, bed settlers, ash and clinker removers, producer blast equipment, humidifers and preheaters and water vaporizers; tar and dust removal and gas cleaning systems, and so on without end. Production of some of the gas power specialties has itself become a separate large business, again repeating steam engine history where the manufacture of steam specialties on the designs of specialists has contributed as much to the success of the steam system as anything done with the main units of boilers and engines themselves. To be sure there still are found new suggestions for a complete scheme of engine or gas producer or power plant, of which the Humphreys gas pump is probably the most striking among the former, and the new Ford com-

bined gas and steam power plant among the latter. These are not, however, typical of the times, though it is quite likely that one or more may foreshadow the next great step in advance which must come as surely as have the others in both steam and internal combustion field, and which may be for the latter as great and as significant as the steam turbine has been for the former.

Today the internal combustion engine and the gas power system occupy a definite place in the scheme of industrial affairs, and are so firmly established that they will never be displaced, though the sphere of influence is sure to be changed. The small power boat is almost universally driven by the liquid fuel type, using gasoline. The use of the internal combustion engine here has doubled the production of the fishing industry, where it displaced sails and has been a strong factor in open air sport. Approximately 400,000 of these motor-boat engines are now in use in this country and they are being produced at the rate of about 150,000 per year according to the National Association of Engine and Boat Mfgrs. Perfection of larger engines, capable of using heavier distillate and fuel oil is proceeding at a surprising rate and trans-oceanic vessels driven by these internal combustion oil engines have ceased to attract attention. According to Lloyd's Register for 1914 there were in service 27 such vessels equipped with Diesel oil engines, aggregating 50,000 i.h.p., and 20 more building. This type has reached the size of 1000 h.p. per cylinder, or 6000 h.p. in six cylinders, all single acting. Practically all the submarines of the world are driven in this way, the earlier ones by gasoline and the later by Diesel oil engines, and it may truly be said that the submarine owes its origin to the internal combustion engine. Of this class in 1913 there were about 323 in use; owned by Great Britain 98, Russia 55, France 42, United States and Germany 39 each, and the rest widely distributed. Boat propulsion by gas producers is yet in the experimental stage, and though some successful installations are on record, these are confined to small or medium sized vessels where weight of machinery is less important than fuel economy, due to the present excessive weight of gas producers. Reduction of gas producer weights is all that is needed to widely extend the size and types of boats that may reap the

advantage of the low fuel consumption, small operating force and cool machinery compartments, typical of this class of power equipment. Light weight of engine per horsepower, high fuel economy and low consumption of water, when driven by gasoline, including all auxiliaries and fuel supply are together responsible for the unprecedented success of the automobile of both pleasure and commercial forms and including the motor cycle at one extreme and the traction engine at the other. In these fields there is no rival; the field is entirely occupied by the internal combustion engine, with the exception of a few but decreasing number of steam tractors built for use where water is plentiful and convenient and coal and wood are very much cheaper than gasoline or kerosene; there is only one style of steam automobile and forty electrics, of small output, left to compete with the four hundred odd automobiles manufactured which use the gasoline internal-combustion type of engine, and with one exception there are no steam aeroplanes or dirigibles.

It is estimated by Wheeler & Shebler that the annual production of gasoline motor cycles is now close to 70,000 and of aeroplanes about 300. The number of automobiles of pleasure and commercial types is estimated for 1914 as 435,000 by Livingstone, 515,000 by Reeves and 650,000 by Anglada, equivalent to a mean round number of half a million a year which represents a yearly value of very nearly $500,000,000. There are 170 producers of gasoline pleasure-cars, 245 of commercial, 77 small or cycle-cars and 27 of gasoline fire-apparatus (Livingstone) in the United States alone. Heavy haulage vehicles or overland locomotives, now called gas or oil tractors when operated on gasoline or kerosene, most of them using either, are now produced by about thirty firms, in sizes ranging from about ten to about sixty horsepower, two horsepower of engine being approximately equivalent to one heavy horse in hauling capacity. No statistics of these most useful vehicles, that are now so large a factor in big scale farming, are available but the production must exceed 10,000 per year, many for export, and the U. S. Bureau of Plant Industry reports that 13,000 were in use west of the Mississippi River at the end of 1913.

Rail transportation, like the large ocean ship, has not yet been affected, though a beginning has been made by the small low speed gasoline locomotive, built up to ten tons weight and ten miles per hour, and by the gasoline direct drive and gasoline-electric passenger car, built self-contained to seventy feet in length and capable of 70 miles per hour speed, both limited to a definite class of service. It is estimated that there are about five hundred of these units in operation, each carrying from twenty-five to three hundred horsepower, one firm alone reporting 160 in successful operation and one unit eleven years old. The economic and industrial effect of the internal combustion engine in these fields is equalled only by that of the trolley car and need only to be mentioned to be accepted and understood not only by engineers but by any one, as every class of society has been affected.

It is in the stationary field that the most curious situation has arisen, for here the greatest advances in design have been made both as to perfection and variety, and yet relatively the least progress in adoption has followed. The reasons are not at all obscure and are all associated with the competition of steam engines directly, in larger sizes, or with electric motors supplied from steam driven or hydro-electric central stations in smaller sizes, and while in some cases relative convenience controls, it is really relative power costs that determine the choice. The internal combustion engine is thermally more efficient, size for size and fuel for fuel, than the steam engine in any size in which it can be built, and the difference in fuel consumption is greater the smaller the size because efficiency of steam systems falls off very rapidly with decrease of size, while that of the internal combustion engine does not. Against this fuel saving by internal combustion engines over steam must be placed the undeniable fact that the former costs more to build, and must have a selected fuel, gaseous or a suitable liquid originally, or must be charged with the cost of gasification of a selected coal in gas producers or with the distillation cost of preparation of a suitable liquid fuel. In addition the repair and attendance costs on the larger internal combustion engines still exceed those of the steam plant, though they are being reduced, and finally the light load operation of gas engines results in greater

sacrifice of full load efficiency than is the case with steam engines. Accordingly, in all those power plant installations where low power cost is of prime importance, the money value of the fuel saving of the internal combustion engine over that of competing steam equipment, which saving is less the larger the size and the smaller the average engine load, is not sufficient to overcome its excess of operating cost and of fixed charges—which excess is greater the larger the size—unless the installation is small enough, the plant load factor large enough, the average individual engine load large enough, or the price of fuel high enough. This is on the assumption that both systems are to use the same fuel at the same fuel price. The power cost balance may be displaced when different fuels are available with different degrees of adaptability; thus gaseous or a suitable liquid fuel favors the internal combustion engine, as these may be directly burned without loss or without special equipment expense, whereas a coking bituminous coal bars the gas producer entirely and favors steam.

Geographical location of the plant or even local ownership may thus be the controlling factor, and favor the internal combustion engine in spite of its natural handicaps of high first cost, low efficiency at light load, or size of plant, as is clear from one or two citations. Oil regions, such as California or Texas, naturally favor internal combustion gasoline or oil engines against steam, unless the plant be too large; when the balance again falls toward steam, partly because large units of the former class cannot yet be built and partly because of decreasing steam plant power costs in these large sizes, especially if the average load per unit is but a small fraction of its maximum. About the same thing is true in the natural gas regions and in places close to a by-product coke oven or blast furnace plant, especially if the power plant is under the same ownership. Equal terms as to fuel are found in the anthracite region as boiler and gas producer can equally well handle this fuel, except that here the cost of fuel is likely to be so low as to be unable to meet excess of fixed charges. Finally, the balance swings the other way where the only available fuel is bituminous coal, especially if it is of the coking variety, or if this fuel is much the cheapest, for here the balance is all in favor of steam.

Against this must be set the condition that favors the internal combustion engine so strongly as to exclude steam competition entirely, and that is the small installation up to say twenty-five horsepower, suitable for isolated electric plants, farm machinery, small shops, or using gas from pipe lines or light liquid fuel such as gasoline or kerosene, since both the heavy oil engine and gas producer are inoperative in these sizes. For such small unit power use the internal combustion engine has no rival in isolated places and is universally used, but in settled districts it has a most potent competitor, the electric motor supplied from the large central station, steam driven or hydro-electric. Against this electric motor competition in small sized units, the internal combustion engine has failed in part to hold its own, just as truly as in large generating plants directly competing, and partly for the same cost reason, though another factor enters, and that is availability or convenience. For example, in fractional horsepower units there is no internal combustion engine at all, so all this service is performed by electric motors. In sizes of a few horsepower each the situation is different as internal combustion engines are available and they can produce power cheaper than the central station can supply electric power up to a certain maximum size. This size depends on local electric rates, and on the price of its own fuel, gasoline and kerosene in suburban or country districts, and illuminating gas from city mains in urban districts. A very large number of these engines are in use; in fact, most of the output of internal combustion engines today is of this class and the number would be larger if they were better designed and built, so as to start more readily, and better balanced, so as not to shake buildings and to have long life and to require less adjustment. As it is, the number of this class produced is put by Stritmatter at 250,000 per year, one firm alone specializing in farm-type gasoline engines having an annual output of about 40,000, and the next largest nearly as many, with upward of a thousand builders in the field, excluding small makers, each producing a few per year. The farm engine has been so widely adopted that without it the food supply of this country could not be produced with less than twice the present farm population. In the state of California alone there are, according to Luitweiler

P. E. Co., some 14,300 internal-combustion engines operating pumping plants, many of them in districts served by hydro-electric transmission lines, and the number is increasing. In the city of Philadelphia there are 1,400 such engines supplied from the illuminating gas mains, averaging about three horse-power, burning 363 million cubic feet of gas per year, but the number is not so large as it should be and is not increasing as fast as electric motors. Greater success against this urban electric motor competition must follow better special design, because the cost favors the gas, at present normal rates of public gas and electric supply, and doubly fast will the change come when fuel gas is made available at rates as low as it can be. Electrical rates are being reduced all over this country while city gas rates are kept up by law to conform to absurd candle power requirements that are relics of a past era.

It thus appears that in this stationary field the internal combustion engine has succeeded in overcoming its competitor only when favored in some way by fuels in kind or cost, and that its own inherent advantage of high thermal efficiency has been insufficient to advance its use, first, in the larger sizes against steam, especially turbines, by reason of first costs, and second, in the smallest sizes against electric motors by reason of lack of convenience and the excessive gas rates that must be charged for the legal requirements of gas candle power. If it were not for the high thermal efficiency, the urban gas engine could not compete as it does at existing rates, but more special design is required to bring the gas engine into its own in competition with the electric motor, just as much as a reduction in fuel gas-rates, and the latter is as possible economically, as the former is technically. That more low-cost true manufacturing-in-quantity of small engines of better design has not been undertaken by engine producers is due to neglect of this most promising field, based partly on a lack of realization of its magnitude and stability and partly on the old idea of engine builders that they must make large units to be successful; an idea justified in the case of steam turbines where both first cost and fuel consumption decrease with size, but not true with internal-combustion engines where fuel consumption is not affected by size over a low minimum, but where first cost is.

Engine builders—prompted by the demands of the blast furnace establishment for blowing and electric engines after the Cockerill's had demonstrated the economic feasibility of doubling the power output from the waste furnace gases over the then standard compound engine—designed, built, redesigned and rebuilt hundreds of large engines, some single, but most double acting, at enormous experimental expense. This, together with gas producer advances, induced practically every large engine builder in both Europe and America to undertake similar big engines, on the belief that these would find a general power plant application, and displace steam, as had been so largely done in the blast furnace plants. Some of these hopes were realized, but most of them failed. In the case of the failures, excepting the few cases of bad design, it must be confessed that the causes could hardly have been foreseen; though it is now clear that the time, money and ability expended might better have been used in developing that yet undeveloped but large and sound field of the small and medium sized engine.

First among the disappointments was the gas producer, which, advancing rapidly at first, abruptly stopped, leaving unfulfilled the early promise of an ability to properly gasify any coal. It attained complete success only with fuels that are practically all fixed carbon, is fairly successful with non-coking bituminous, and to a still less degree with lignites, peats and fuel oils, but is always large and heavy per horsepower. Against this must be set the great advance in steam turbines, stimulated by the gas power plants and closely approaching the latter in coal consumption, with plant costs less than half, an unbeatable handicap with the low load factors that maintain in these large plants, especially when coal is not too high in price. This competition was a complete surprise, as was also the discovery that large gas engines must be extremely heavy and cannot be built at all beyond a cylinder diameter of about 50 inches, corresponding to about 1500 h.p. per double acting four cycle cylinder, and 2000 h.p. per two cycle cylinder. These engines weigh, as built in Europe, about 300 lbs. per h.p., and as built here over 400 lbs. per h.p., reaching in one case almost 600 lbs. per h.p., and cost from 6 to 8 cents per pound, making

the cost per horsepower range from \$25 to \$45, against which might be noted turbine and electric generator costs under \$10. To be sure, smaller engine weights are recorded but usually these lighter engines have failed to give satisfactory service. In one case a large, single acting engine sold for \$30 per h.p. and weighed 200 lbs. per h.p., bringing 15 cents per lb., at which price construction is profitable to builder though not to buyer, whereas it is profitable to neither at the weights and the prices of the large, long-life engines. In spite of a general lack of success with the large producer gas plant, some considerable installations have been made and more undoubtedly will be. As estimated by Fernald, there are in this country about 39,000 h.p. in sizes over 500 h.p., and 95,000 h.p. in sizes under this, a total of 144,000 h.p. using anthracite, 130,000 h.p. using bituminous and 15,000 h.p. using lignites; or a total of about 290,000 h.p. in all sizes, and this is probably low. The ratio of the total internal combustion engine horsepowers in medium and large sizes operating on all fuels, to the total for producer gas for the whole country is probably about the same as for output of one typical large firm. This firm reports a total sale of 214,000 h.p., of which 22% were for producer gas, about equally divided between single and double acting; 50% for natural gas, 3/5 single and 2/5 double acting; 17% for blast furnace and coke oven gas, and the rest on illuminating gas or gasoline. Applying the ratio of 22% to Fernald's figure gives a total of 1,300,000 h.p. in use in medium and large sizes on all fuels, and exclusive of the small sizes previously reported. For the large engines alone, over 500 h.p. each, Freyn estimated in 1913 a total of 500,000 h.p. in use, largely for blast furnace and natural gas, the two favoring fuels. The class of service rendered is tending more toward manufacturing or other industrial establishments than toward central stations, as is right and proper, and more in numbers than in horsepower, as the average horsepower here is small. The present division of capacity for one representative builder is: manufacturing 58%; central station and electric railway 20%; isolated electric plants 10%; natural gas pumping 12%; while in numbers of engines the fraction devoted to manufactures is much larger than 58%, probably exceeding 75%.

The wide open field for the medium sized and small unit, yet unoccupied by the internal combustion engine, is clearly seen by a glance at Table I, Power Statistics, prepared from the census reports. It is in this field that the competition of the steam turbine, so strong in largest sizes, and of the electric motor and its central station in the smallest, is least effective. Here the full advantages of the gas power system are realizable not only because of the engine economy itself, but also because so many of these plants use considerable fuel for heating purposes, and this service producer gas can also directly and economically satisfy. In four large fields of power use and together using over 37,000,000 h.p., only 1,850,000 h.p., or 5%, is from internal combustion engines. This power contributed by internal combustion engines is: for manufactures only 2.1% of 19,524,000 h.p. total; mines and quarries, 8.05% of 5,470,000 h.p.; electric central stations, 1.49% of 8,217,000 h.p.; street and electric railways, 0.67% of 3,894,000 h.p. The average horsepower per installation for these groups is: manufactures, all systems 93.5 h.p., gas power 23.8 h.p.; mines and quarries, all systems 51 h.p., gas power 23 h.p.; electric central stations, all systems 690 h.p., gas power 97.5 h.p.; street and electric railways, all systems 1550 h.p., gas power 520 h.p. From this it is clear that for street and electric railways, as a class, the large average h.p. bars the internal combustion engine because steam economy is fairly good and load factor only 17%, making a big fixed charge handicap. The situation is similar though not quite so bad for the central electric station where the service is one of pure power generation, as is also that for mines and quarries. This is not at all the case for manufactures, which, though using as much power as the other three groups together, also in addition require a great deal of direct heat from fuel for both building warming and for its processes.

To operate a manufacturing establishment, power is required, but so is heat at both low and high temperatures, and so also is light. Moreover, the power itself is normally required for application at many points instead of one, a condition favoring many small engines instead of one large one and a condition easily met by internal combustion engines. Where steam is now employed in these manufacturing establishments,

TABLE NO. 1.

Power Statistics.

Estimated from Census Reports by Rates of Increase.

Power system	Item	Manu-factures 1913	Mines and Quarries 1913	Elect. Central Stations 1913	Street and Elec. Railways 1913	Boats 1906	Telephones 1907
All classes of power	No. of units	208,750	107,180	12,070	2,505	9,920	488
	Total hp.	19,524,000	5,470,000	8,217,000	3,894,000	3,451,657	5,493
	Av. hp. per unit	93.5	51.0	680.0	1,550	348	11¼
Steam power	No. of units	152,400	76,150	7,800	2,040	6,765	16
	Total hp.	16,620,000	16,620,000	4,645,000	5,400,000	3,378,453	8.51
	Av. hp. per unit	109.0	61.0	690.0	1,630	500	53
Water power	No. of units	13,350	1,360	3,020	415	....	....
	Total hp.	1,865,000	145,000	2,695,000	548,000	....	....
	Av. hp. per unit	140	107	890	1,320	....	....
Gas power (Internal Combustion Engines)	No. of units	43,000	29,670	1,250	50	3,155	472
	Total hp.	1,021,000	680,000	122,000	26,000	73,204	4,642
	Av. hp. per unit	23.8	22.9	97.5	520	23.2	9.8
Percent of total hp. that are Int. Comb. Engines, all classes		5.2	8.05	1.49	.67	2.1	84.5
Percent of total No. that are Int. Comb. Engines, all classes		2.1	27.8	10.7	2.0	31.8	97

Notes. **Manufactures** here include industrial establishments producing over $500 worth of standard goods per year for wholesale trade or machinery on order and exclude such as dressmaking, tailor, millway, building trades, hand trades, stores, using machinery and power.

Mines and Quarries cover all claims of mines, quarries, petroleum and gas wells.

Central Electric Stations include all producing electric current for distribution and use in lamps, heaters and electric motors. Average load factor is 17.6%.

Street and Electric Railways include all railways except steam railroads.

Boats include all American coast and inland vessels over 5 tons, except fishing, houseboats and Federal Government vessels.

Telephones include all commercial public lines.

a central power plant is the rule for economy, and exhaust steam is used for all low temperature heating, though for furnaces fresh coal or oil fuel must be separately burned.

The very argument that justifies centralization of the steam engines, applies to the gas system in the centralization of the gas producer plant, but not to the engines. The high efficiency of small gas engines calls for de-centralization and gas pipes from a central producer plant supplying distributed engines and heating appliances for both high and low temperature service.

This is the true and best field for gas power, but one not yet fully grasped,—the builder of big engines regarding it as somewhat beneath his dignity to make small ones and the maker of small engines lacking the necessary engineering organization to undertake a complete installation with piping, furnaces and gas producers. Transmitted electric power cannot compete with this even in power cost alone, and is doubly excluded when heat is required, though lighting gives it an advantage. The steam plant has had an advantage, when large amounts of low temperature heating are required, in the utilization of exhaust steam, making power a by-product for the whole year or in the winter season, but this advantage disappears as soon as satisfactory producer-gas-fired heating appliances become available on the one hand, and jacket water and engine exhaust heaters, which are now appearing, come into use.

One of the large factors in the introduction of this gas power system in manufacturing establishments is the development of producer gas heating equipment as auxiliary thereto, and supplied from the same gas producer plant that furnishes gas for engine power, and very great progress has been made in this field by the development of the surface combustion system by Bone in England, Schnabel in Germany and Lucke in America. According to it, gas and air, automatically supplied in combining proportions, is burned in specially arranged fire beds or furnaces under perfect control, yielding oxygen-free products of complete combustion, and with a very large amount of heat in the radiant form, suitable for efficient absorption, at any rate of combustion from that suitable for toasting crackers up to melting heats for iron, without preheating or enrichment

of producer gas. In addition to these surface combustion heating appliances, only one new element, and that a similar development in the field of producer gas illumination, is needed to perfect for the industrial world the complete gas power system.

Illumination through mantle lamps by producer gas is not yet a commercial reality, but from a series of experiments recently conducted for the writer by the Welsbach Company there is every reason to believe that it is on the way. Using the the same gas burner and mantle for gases ranging in calorific value from 629 to 261 B.t.u. per cubic foot, the candle power per B.t.u. was almost constant, ranging between 0.034 and 0.046 for this wide range of gases, though the candle power per cu. ft. ranged from 24 to 10 in round numbers. To be sure, the lowest calorific value, 261, is still higher than that of producer gas, which may go as low as 110, but the principle seems to be well established that the candle power per B.t.u. falls off very little, certainly the cost per B.t.u. in gas falls faster, so very cheap mantle lighting is promised by these figures, particularly where special mantles and burners are designed for this weak gas.

Half the skill, effort and money lost in the hopeless effort to force the present type of large gas engine against the overwhelming competition of the steam turbine for large central station work, if applied to the mechanical perfection and production of small and medium gas engines, gas producers, heating appliances, and auxiliaries, as has been done with electric motors or automobile engines, would have today resulted in as great an adoption as in the automobile and farm field, simply because the economic conditions are right.

To meet the competition of steam plants in large sizes and of electric motors supplied from large steam or hydroelectric central stations in small sizes, two separate and distinct developments, both of which are understood and more or less under way, must be carried through. For the former, engine weights and cost per horsepower must be brought down and the gas producer improved by reduction of size and by a greater independence of kind of fuel fired. For the latter, the small gas producer must be found, or in its place central gasification plants established in important centers with long distance dis-

tribution systems of fuel gas pipe lines. To adequately reduce engine costs seems to require a radical change in type of engine, and while many are at work along lines ranging from the use of steel for cylinders through changes of arrangement, such as the English Fullagar engine, up to the more distinctive internal combustion gas or mixed gas steam turbine, there are no conclusive results. All that can be said is that the need of cost reduction for large plant competition is clearly understood, but as the reduction must be material, to at least half the present costs, something so radical is required that it can hardly be expected for some time, if at all.

Pending the efforts of designers and inventors to solve the problem of reduction of weight and cost of large gas engines, it is most important that a broad and deep study of the question of necessity be undertaken, for it really seems as if the necessity is more fancied than real. Where are large engines really required and in what numbers? Is the present demand based on actual requirements of service, or is it influenced by steam conclusions? It does not require much investigation to find that power, while now so generally generated in large units, is almost universally applied in small units, a distribution or transmission system forming the tie between single big generators and the multitude of points of useful application of power. No better proof of this in a general way is available than the very large average size of electric generators and the almost tiny average electric motor now regularly produced. Small gas engines, if they could be directly applied to the work, would eliminate any necessity whatever for 90% of the large ones now demanded as a relic of steam centralization practice, and if the efficiency and reliability characteristics of small gas engines teach anything they teach and insist upon the principle of de-centralization, absolutely contrary to the steam lesson. Small gas engines are reliable, more reliable than small steam engines as the numerous reports of Longridge, based on English insurance of both types, have repeatedly proved. These small reliable engines can be built cheaply now, and if produced in the quantities in which they should be used, and in large shops under a true system of manufacture, they can be both improved and cheapened further, and become, as they should be, real

direct competitors of electric motors for all stationary service. Instead, therefore, of forcing an effort, so far a failure, to build big gas engines to compete with big steam turbines, in central power stations, effort should be diverted to the perfection and production of small sizes to compete directly with the electric motor, but generating power effectively and reliably at the point of use, instead of generating in a distant central station with two transformations, one into and one back from electrical energy with a copper loss in transmission line between.

With such an attractive prospect, so fundamentally sound from practical and economical standpoints, and with so little done to promote it, there must have been some hindrance, some obstacle, and in this case it lies only in the development of a suitable fuel gas distribution system to replace and compete with the present highly developed and vigorously pushed central steam and hydroelectric systems. Proper application of the internal combustion engine never can come from any concentration of attention on the engine itself, in fact, that is just what has delayed matters so long. It can come only with the general acceptance of the principle of the gas power system as a system, in which the engine is but one unit, and it is the gas power system as a system, on a large scale, that can compete with the hydroelectric system, or with the central steam electric system, where the gas engine alone finds some difficulty in its direct competition with steam engines and water wheels in large units or with the electric motor in small ones.

At the present time the way is open for an immediate extension of this gas power system along this line of lesser resistance,—that of fuel gas distribution from central gasifying plants, supplying both domestic and industrial establishments with cheap gaseous fuel for heat, power and even light, at prices so near that of raw fuel that users find the fuel gas more economical than coal. A start in this direction has been made in England, that is worthy of notice and of duplication elsewhere in this country. At Dudley Port, South Staffordshire, there has been in operation for about ten years a bituminous gas producer plant, now with eight producers, with two in reserve, each ten feet in diameter, gasifying 20 tons of coal per day

with 50% overload capacity on low ash coal, and sending out gas under 5 to 7 lbs. sq. in., pressure through a 36″ diameter main to 37 miles of smaller pipe, the longest line being 6½ miles. In the district served by these lines all individual producer installations, nearly fifty in number, were shut down and gas purchased at a price averaging 1.8 d. per 1000 cu. ft., and ranging from 2¾ to 1½ d., the heat value being ¼ that of city gas. There is not the slightest reason in the world why such plants should not pay here, and there is even more reason why similarly centralized by-product coke oven plants should pay, sending out coke oven gas through long mains, at least throughout one town or through a group of reasonably close towns. The coke yield could be marketed as such, or when coke demand failed, it could be gasified in producers and the coke producer gas mixed with the coke oven gas, giving a fuel gas ranging both sides of 300 B.t.u. per cu. ft., at which value mantle illumination by gas lamps is now feasible; high or low temperature gas burning appliances are highly economical, whether for household heating or cooking or industrial building warming, steam raising, or furnace operation, and which gas is perfectly satisfactory for high economy of power generation in any size engine, from the smallest to the largest.

Such a central gas plant and fuel gas distribution system would do for the gas burning engine just what has been accomplished for the liquid fuel engine by the present improvements in oil distillation, such as the Burton process, increasing the yield and decreasing the price of gasoline by converting the heavy fractions of the oil into the lighter. From the engine standpoint this is precisely equivalent to converting a heavy expensive oil engine that cannot be built in small sizes at all, into a single cheap gasoline engine that can be built as small as any one wants.

The gas power system, as thus conceived, is a big thing, and its undertaking a problem in order of magnitude somewhat equivalent to a railroad, requiring great capital, serving all classes of society, as useful to the factory with its furnaces and engines as to the home with its cook stove and heaters. It is a fuel distribution system based on a primary fuel manufacturing process to get coal or oil into gaseous form, so that it may not

only be most economically distributed at lesser costs than by coal car on rails and coal and ash wagon on road and streets, but also when delivered to consumer be equally available for economical power, heat and light.

The future of the internal combustion engine in the stationary field is bound up in the fuel problem, especially so with the modern conception of the fuel problem, which is, most economical use of fuel from every standpoint. Direct combustion of the cheapest raw fuel obtainable may not be most economical, and certainly will not be if that fuel cannot be efficiently burned in apparatus capable of efficiently producing the desired result from the heat.

From the fuel utilization standpoint the world has been slowly learning a lesson, the lesson of gasification as an essential prerequisite to efficient combustion. This began with the introduction of producer gas for metallurgical furnaces formerly burning coal directly and has regularly but slowly grown. To this more recently has been added the principle of gas-air mixing in combining proportions before combustion and in the power field this is the direct contribution of the internal combustion engine; in the heating field the same conclusion has been demonstrated by surface combustion appliances, and finally in the lighting field by the Welsbach mantle. In proportion as more and more of the country's fuel supply is gasified or put into the equivalent form of vaporizable liquid fuel, so may its progress in efficient fuel utilization be measured. A brief review of the present use and treatment of the whole fuel supply will show to what extent progress has been made, how much further the process may be carried, and so measure the extent to which the country may yet advance in efficient, economical distribution and utilization.

The total production of anthracite in 1913 (Parker, U. S. Geo. Sur.) was 89,677,000, and bituminous 480,371,000 short tons, making a total of 570,048,000 short tons. Against this the imports and exports must be charged to get home consumption and these amounts are (Mineral Industry), anthracite exported 4,154,000 tons, with no imports, leaving 85,523,000 tons of anthracite for home consumption, of which 8,650,000 tons were burned at the mines and 1,800,000 locally consumed, or a total

of 10,450,000 tons, failed to reach the general market but yet was consumed. Of bituminous coal the exports were, 25,687,-000 and imports, 1,414,000 tons, equivalent to a net export of 24,273,000 tons and leaving 456,100,000 short tons of bituminous for home consumption.

For the same year the liquid fuel production figures are (Day, U. S. G. S.) 248,446,000 bbls. of 42 gallons each, which is 65.12% of that of the world, and which brought an average price of 95.4 cents per bbl. Against this must be charged imports of 17,923,000 bbls. and exports to Alaska, Hawaii, Philippines, Porto Rico of 1,380,000 bbls., and to foreign countries 74,227,000 bbls., totaling 75,607,000 bbls. exported, from which substracting the imports leaves the net results an export of 57,684,000 bbls. and a home consumption of 190,762,000 bbls.

Similarly, for natural gas and natural gas gasoline the production and consumption are (Hill, U. S. G. S.) 581,898,-239,000 cu. ft. of natural gas sold at an average price of 15.10 cents per thousand, of which 32% was consumed for domestic use and 68% for industrial uses at an average price of 27.33 and 9.4 cents per thousand, respectively. At the same time there were produced and used 24,061,000 gallons or 573,000 bbls. of gasoline from 9,890,000,000 cu. ft. of this gas, or 2.42 gallons per thousand feet from about 1.7% of the gas.

The average calorific value of the natural gas at various places is given at W. Va., 1140; Ohio 910; Oklahoma and N. Y. 1013; Texas 748; Kansas 950; Louisiana 906; Indiana 1025; Arkansas 964; S. Dakota 868; Utah 944; and may be taken for general comparative purposes for the whole supply as 950. Similarly, for the crude oils and their products the average calorific equivalent may be based on 19,000 B.t.u. per lb.; 7.5 lbs. per gal. and 42 gals. per bbl.; which gives 142,000 B.t.u. per gal. and 6,000,000 B.t.u. per bbl. in round numbers. For the coal the calorific value would be about 14,500 B.t.u. per lb. of fixed carbon contained, with a reduction for ash and moisture and an addition for the hydrocarbon volatile especially for the bituminous coals which constitute the bulk of the consumption, and in the absence of statistics this may be taken at the round number of 14,000 B.t.u. per lb. for the whole or 28,000,000 B.t.u. per ton. With these figures the oil and gas consumption can be

reduced to the equivalent tons of standard coal for purpose of comparison as follows: Adding to the petroleum products consumption of 190,762,000 bbls., the 573,000 bbls. gasoline from natural gas, gives 191,335,000 bbls. of liquid hydrocarbon fuel. Each barrel of this is equivalent to 6/28 or 0.215 tons of standard coal or approximately half the anthracite production. Of the natural gas, each million cu. ft. yielding 950,000,000 B.t.u. is equivalent to 950/28 or 34 tons of coal, and the total production of 581,898,239,000 to 581,898 x 34, or 19,785,000 tons of standard coal. On a similar basis the denatured alcohol yielding 100,000 B.t.u. per gal. is equivalent to 100,000,000 B.t.u per 1000 gals. or $100/28 = 3.58$ tons of coal, and the whole production of 10,000,000 gallons to $10{,}000 \times 3.58 = 35{,}800$ tons of standard coal.

A summary of the natural fuel consumption directly and as manufactured into liquid fuel distillates or gas before consumption is given in Table II, "Fuel Statistics", as nearly as can be estimated from various disconnected facts and items. In this table there is introduced the arbitrary unit of tons of standard coal to get a measure of all fuel in the same units and which gives a grand total of 563,617,015 tons standard coal for U. S. for the year 1913. Of this there was burned directly in and about the mines, by railroad locomotives, by private consumers and by the manufacturing industries, 504,167,000 tons, or almost exactly 90%, distributed as follows for coal: 39,900,000 tons at mines; 142,512,000 by railroads; 121,781,000 private consumers; 177,-904,000 manufacturing industries; for oil in terms of tons of standard coal the figures are 22,070,000 as fuel oil, crude tar and residue. With the exception of a small amount produced as lubricating oil, the rest, or 10% of the total, was gas originally or manufactured into gas or vaporized distillate, and while this seems pitifully small, it must be remembered that not so very long ago in the world's history this was zero, and even at the present low value of 1/10 of the total the gross amount is pretty big, being over fifty million tons of standard coal in the form of natural gas, blast furnace gas, coke oven gas, producer gas, retort coal gas, carburetted water gas, oil gas, gasoline, kerosene, gas oil, alcohol, acetylene and a small amount of benzole (equivalent to about 16,000 tons standard coal) not recorded.

TABLE II FUEL PRODUCTION, CONSUMPTION, DISTRIBUTION AND COAL EQUIVALENT IN THE UNITED STATES FOR 1913. (C.E. LUCKE, COLUMBIA UNIVERSITY)

PRIMARY FUELS PRODUCED	EXPORTS LESS IMPORTS	NET PRIMARY FUELS	PRIMARY FUEL OR PRODUCT AND AMOUNT	EXPORTS LESS IMPORTS	TOTAL AMOUNT CONSUMED IN UNITED STATES	UTILIZATION OF FUEL	GASEOUS	COAL EQUIVALENT TO HEATING POWER OF FINAL FUEL PRODUCTS AS ULTIMATELY CONSUMED	PERCENT COAL EQUIVALENT OF TOTAL COAL EQUIVALENT
COAL 570,048 000 TONS	28,427,000 TONS	541,623,000 TONS — ANTHRACITE 85,523,000 TONS	COAL 476,772,500 TONS		* 476,772,500 TONS	39,900,000 TONS OF COAL WERE USED BY AND ABOUT MINES		Tons-39,900,000	7.0800
						142,512,000 TONS OF COAL WERE CONSUMED BY RAILROADS		142,512,000	25.3000
						121,781,000 TONS WERE USED BY PRIVATE CONSUMERS		121,781,000	21.6000
						COAL & COKE: 177,904,500 TONS (LARGELY COAL) WERE USED BY MANUFACTURING INDUSTRIES & STEEL WORKS EXCEPT BLAST FURNACES		177,904,500	31.5500
						31,000,000 TONS COKE WERE USED BY STEEL WORKS, PRODUCING 2,139,000,000,000 Cu.Ft. OF BLAST FURNACE GAS	✓	7,273,000	1.2930
		BITUMINOUS 456,100,000 TONS				700,000 TONS, MAINLY ANTHRACITE AND COKE WERE USED FOR 119,000,000,000 Cu.Ft. OF PRODUCER GAS FOR ENGINE USE	✓	553,000	.0982
						9,000,000 TONS BITUMINOUS COAL WERE USED FOR 1,530,000,000,000 Cu.Ft. OF PRODUCER GAS FOR FURNACE USE	✓	7,120,000	1.2640
			64,850,500 TONS COAL BITUMINOUS — COKE 49,300,000 TONS	895,000 TONS	48,405,000 TONS	2,380,000 TONS OF ANTHRACITE & COKE WERE USED FOR THE PRODUCTION OF 119,165,270,800 Cu.Ft. OF CARBURETTED WATER GAS	✓	2,660,000	.4730
			RETORT COAL GAS 49,505,004,200 Cu.Ft.		49,505,004,200	49,505,004,200 Cu.Ft. OF RETORT COAL GAS WERE USED FOR LIGHT, HEAT AND POWER	✓	1,105,000	.1963
			BEEHIVE COKE OVEN GAS 236,000,000,000 "		236,000,000,000 Cu.Ft.	236,000,000,000 Cu.Ft. OF BEEHIVE COKE OVEN GAS WERE WASTED AT THE WORKS	✓	4,640,000	.8240
			BY-PRODUCT COKE OVEN GAS 87,500,000,000 "		87,500,000,000 Cu.Ft.	87,500,000,000 Cu.Ft. OF BY-PRODUCT COKE OVEN GAS WERE USED FOR LIGHT, HEAT AND POWER	✓	1,720,000	.3050
PETROLEUM 248,446,230, BBLS	-12,433,662 BBLS	260,879,892 BBLS	RESIDUE 130,308,168 BBLS	27,462 668 BBLS.	102,845,500 BBLS.	83,000,000 BBLS., OF FUEL OIL WERE USED AS FUEL OF WHICH RAILROADS USED 33,004,815 BBLS. AND NAVY 500,000 BBLS.		17,800,000	3.1600
						19,845,500 BBLS., OF RESIDUE INCLUDING FUEL OIL, TAR ETC., WERE USED FOR OTHER PURPOSES		4,270,000	.7575
			LUBRICATING OIL 35,076,224 BBLS.	5,116,224 BBLS.	29,960,000 BBLS.	29,960,000 BBLS., OF LUBRICATING OILS AND GREASES, WERE USED FOR LUBRICATING PURPOSES		6,440,000	1.1420
			GAS OIL 26,149,500 BBLS.	7,620,000 BBLS	18,529,500 BBLS	7,120,000 BBLS., OF GAS OIL WERE USED TO MAKE 18,703,140,500 Cu.Ft. OF OIL GAS FOR LIGHT, HEAT, ETC	✓	400,000	.0710
						11,350,000 BBLS., OF GAS OIL WERE USED IN CARBURETTING WATER GAS (LAST ITEM UNDER COAL AND COKE)	✓		
						59,500 BBLS., OF GAS OIL WERE USED TO PRODUCE 620,000,000 Cu.Ft. OF BLAU AND PINTSCH GAS	✓	33,200	.0059
			KEROSENE 42,402,500 BBLS.	25,402,500 BBLS.	17,000,000 BBLS	17,000,000 BBLS., OF KEROSENE WERE CONSUMED FOR ILLUMINATION, ETC.	✓	3,530,000	.6270
			GASOLENE 26,943,500 BBLS.	4,516,500 BBLS.	23,000,000 BBLS.	19,500 BBLS., OF GASOLENE WERE USED FOR THE PRODUCTION OF 136,639,300 Cu.Ft. OF GASOLENE TOWN GAS	✓	3,415	.0006
NATURAL GAS 581,898,23° 000. cf		581,898,239,000 CU.FT	GASOLENE 573,000 BBLS			22,980,500 BBLS., OF GASOLENE WERE CONSUMED BY GASOLENE ENGINES AND OTHER MEANS	✓	4,150,000	.7360
			NATURAL GAS 581,898,239,000 Cu.Ft.		581,898,239,000.	581,898,239,000 Cu.Ft., OF NATURAL GAS WERE CONSUMED FOR LIGHT, HEAT AND POWER	✓	19,785,000	3.5100
OTHER			ALCOHOL 10,000,000 GALLONS		10,000,000 GALS.	10,000,000 GALLONS OF ALCOHOL WERE CONSUMED IN THE MANUFACTURING INDUSTRIES		35,800	.0063
			ACETYLENE 19,587,600 Cu.Ft		19,587,600 Cu.Ft.	19,587,600 Cu.Ft OF ACETYLENE GAS WERE PRODUCED FOR ACETYLENE TOWN GAS CONSUMPTION	✓	1,100	.0002
							TOTAL	563,617,015	100.0000

* TO THIS AMOUNT MUST BE ADDED, 64,850,500 TONS OF COAL USED FOR RETORT GAS AND COKE PRODUCTION

TONS = 2000 LBS. BARRELS = 42 GALLONS

PERCENT OF TOTAL COAL EQUIVALENT GASIFIED, 9.4042

Some of the more important of these items are separately examined below.

Coke Oven Gas. In 1913 there were produced in the U. S. (Statistical Abstract of U. S.) 49,300,000 short tons of coke. The imports amounted to 115,000 tons and the exports to 1,010,000 tons, while the coke consumed was 48,405,000 tons; of this amount 3,460,500 tons were produced as a by-product from retort coal gas making, leaving 44,944,500 tons produced in coke ovens. About 73% of this coke, or 32,800,000 tons, was made in the old beehive ovens which waste all the gas, and 27%, or 12,144,500 tons, in the by-product ovens, which leave a considerable surplus over that required for coking. This is a most significant condition in view of German practice, which is entirely devoted to the by-product system, as must be the case here also before long. While the statistics report a surplus coke oven gas production of only 64,553,941,000 cu. ft., the amounts appears to be larger according to data from Blauvelt and Ramsberg, on proper yields per ton of coal and quantity of coal used. Taking the average figures of practice of coke yield equal to 75% of coal, and the average surplus gas as 5400 cu. ft. per ton of coal of average calorific value 550 B.t.u. per cu. ft. or 3,000,000 B.t.u. net available heat of gas per ton of coal, which is 60% of the total produced, the rest, 40%, being used in coking, the following figures were obtained.

Tons	Beehive ovens	43,700,000
Coal	By-product ovens	16,200,000
Coke	Total	59,900,000
Cu. ft.	Beehive oven gas wasted	236,000,000,000
Coke-oven	By-product oven gas available	87,500,000,000
Gas produced	Total (73% wasted, 27% available)	323,500,000,000
Tons of standard	Beehive oven gas wasted	4,640,000
coal equivalent to	By-product oven gas available	1,720,000
surplus gas	Total (73% wasted, 27% available)	6,360,000

Blast Furnace Gas. Approximately one ton of coke is used per ton of iron produced and yields 150,000 cu. ft. of gas of average calorific value 95 B.t.u. per cu. ft. Of this, some is required to operate the furnace as follows: 35% in hot blast stoves; 5% leakage; 12% for gas powered blowing engines and

2% for electric operation of auxiliaries, a total of 54%, leaving for general fuel purposes 46% or 69,000 cu. ft. of gas per ton of iron. The iron production for 1913 (U. S. G. S.) was 31,000,-000 tons, so that the gas produced amounted to 4,650,000,000,-000 cu. ft. total, of which 2,139,000,000,000 cu. ft. were available for general purposes and 2.511,000,000,000 were required for the operation of the blast furnace auxiliaries. As each million feet yields 95,000,000 B.t.u. it is equivalent to 95/28 or 3.4 tons of standard coal, the gas production was equivalent in heating capacity to 15,810,000 tons, of which there was returned to the furnace 54% or 8,537,000 tons, leaving a coal equivalent for general combustion as gas of 7,273,000 tons of standard coal.

Retort Coal Gas. As with coke oven gas, the yield varies both with temperature and time of heat and, of course, with the coal volatile, but a good average round number (Lewes) is 10,-000 cu. ft. of gas per ton of coal with a calorific power of 625 B.t.u. per cu. ft., or 6,250,000 B.t.u. in gas per ton of coal. This gas yield is 17% by weight of the coal, the remainder being coke 70%, tar 5% and tar liquor 8%. In the United States the consumption of coal gas during 1913 was approximately 49,-505,004,200 cu. ft. At an average calorific value of 625 B.t.u. per cu. ft., each million cu. ft. becomes equivalent to 22.3 tons and the total consumption to 1,105,000 tons of standard coal. On the basis of 10,000 cu. ft. of gas per ton of coal the amount consumed would have required 4,950,500 tons of coal, which yielded 3,460,500 tons of coke available for sale or for water gas making.

Water Gas, Blue and Carburetted. In this process both solid and liquid fuel enter as raw materials, the solid being as nearly as possible fixed carbon in the form of anthracite, or coke from coal gas retorts, and the liquid being a heavy petroleum distillate between kerosene and lubricating oil, generally called gas oil. The approximate consumption of this gas during 1913 amounted to 119,165,270,800 cu. ft. The average calorific value may be taken as the same as for coal gas, for present purposes, which is equivalent to 22.3 tons of coal per million cu. ft., thus the total production becomes equivalent to 2,660,000 tons. On the basis of 40 lbs. of coal or coke per 1000 cu. ft. or 20 tons per million cu. ft. of gas, the output accounts for 2,380,000 tons

of coal and the basis of 4 gallons of oil per 1000 cu. ft. accounts for 476,500,000 gallons (11,350,000 bbls.) of gas oil, which with a value of 6,000,000 B.t.u. per bbl., becomes equivalent to 2,430,-000 tons of standard coal.

Producer Gas. In 1913 there were consumed approximately 700,000 tons of coal in producers for the production of gas, utilized in gas engines. With an average yield of 170,000 cu. ft. per ton of coal, the total gas yield was 119,000,000,000 cu. ft. Using a value of 130 B.t.u. per cu. ft. each million cu. ft. becomes equivalent to 4.65 tons and the total to 553,000 tons of standard coal. During the same year there were used approximately 9,000,000 tons of coal in producers for the production of furnace gas. Using the same yield and heating value, this is equivalent to a total yield of 1,530,000,000,000 cu. ft., which is equivalent to 7,120,000 tons of standard coal.

Oil Gas. This is produced by destructive distillation of heavy petroleum distillate gas oil in red hot retorts under two more or less equivalent processes so far as initial treatment is concerned, the Blau and Pintsch, the former producing 20,000,-000 cu. ft. in four establishments, and the latter about 600,000,-000 cu. ft. in about 90 plants. As a mean value for the yield is 25 cu. ft. of gas per gal. oil, this accounts for the consumption of 2,500,000 gals. (59,500 bbls.). Using as an equivalent in heating value 1500 B.t.u. per cu. ft., each million feet becomes equivalent to 53.5 tons of coal and the whole output to 33,200 tons of coal. In the town-illuminating gas industry there were consumed in 1913 approximately 18,703,140,500 cu. ft. of gas made from gas oil by all processes. Taking a mean value of the yield as 62.5 cu. ft. of gas per gallon of oil, this accounts for the consumption of 299,000,000 gallons (7,120,000 bbls.). Using as equivalent in heating value 600 B.t.u. per cu. ft., each million cu. ft. becomes equivalent to 21.4 tons of standard coal and the whole consumption to 400,000 tons.

The total amount of oil gas consumed in the various processes of gasification was 7,179,500 barrels, and the total standard coal equivalent of gaseous products was equal to 433,200 tons.

Gasoline Gas. Of this gas there were sold by so-called gasoline town plants 136,639,300 cu. ft. in the U. S. during 1913.

With an average value of six gallons of gasoline required per 1000 cu. ft. of gas, the quantity of gasoline consumed for this purpose was 819,834 gallons or 19,500 barrels. Using a heating value of 700 B.t.u. per cu. ft. of gas, the equivalent coal per million cu. ft. becomes 25 tons, and 3,415 tons of standard coal for the total amount.

Alcohol. Alcohol is the fuel toward which all eyes turn as the fuel of the far distant future to follow coal supplies, and the gas power system as that by which it may be utilized. While almost any starch or sugar producing crop may be made to yield ethyl alcohol, 90% is perhaps best produced from potatoes, and this will serve as an illustration. From an average American acre the yield is 275 bushels (Germany over 400) and this will make almost 180 gallons of 90% ethyl alcohol, which is about equivalent to 30 gallons per ton of potatoes and 6 tons per acre. Used in tractors this alcohol will plow the land with about one-half of one per cent of its yield. In spite of this, there is practically none used today, though the law permits the sale, tax free, of denatured ethyl alcohol. The reasons for this are purely economic and peculiar to the U. S., as also is the case with respect to benzol, the coal tar product, which could be produced in large quantities but is not. Neither of these will come without an increased yield of raw materials, potatoes, for example, in one case and coal tar in the other, together with an increased price for competing fuels, and a lessening demand for each as raw materials in the chemical industries. The denatured alcohol produced in 1913 amounted to 10,000,000 gallons of calorific value 12,500 B.t.u. per lb. and 8 lbs. per gal. approximately or 100,000 B.t.u. per gal. It must be noted here, however, that an appreciable amount, if not most of this, was used as a solvent or raw material for chemical manufacture instead of fuel. Since all this might be used as fuel, each 1000 gallons becomes equivalent to 3.58 tons of standard coal and the total amount to 35,800 tons.

Acetylene. Although this gas is not derived from the gasification of coal or oil, its production depends upon the natural resources of the earth, since the calcium carbide from which it is produced by the addition of water, is made by current generated by the utilization of water power. According to Brown's

directory the approximate amount sold for consumption during 1913 by town gas plants was 19,587,600 cu. ft. The average calorific value is 1575 B.t.u. per cu. ft., thus each million cu. ft. of gas becomes equivalent to 56.2 tons of standard coal and the total to 1,100 tons, an almost negligible quantity.

Petroleum Products. According to Day (U. S. G. S.) the production of crude petroleum in the U. S. in 1913 was 248,446,230 barrels, 65% of the world's supply. Some of this, 30.4%, was exported largely in the form of kerosene lamp oil, but these exports were offset by imports of crude oil from Mexico, amounting to 7.2% of our production. The net amount left for home consumption was thus 76.8% of the production, or 190,762,000 barrels. It would not be far wrong to assume that practically all of this (except the lubricating oils, paraffine wax, tars, and asphalt), including the light distillate, gasoline, the heavier one, kerosene, and the still heavier ones, variously known as distillate, solar oil and gas oil, is available for one or another of the elements of the gas power system. While formerly the production of any one of the light distillates was limited to the natural peculiarities of the oils, ranging for gasoline from 20% for the Pennsylvania type to 2% for the Mexican, modern distillation improvements by the use of high pressures, of catalyzers and of reagents, seem to warrant the prediction of almost any yield of any distillate at will and even to give a semblance of reality to the dream of hydrogenation of carbon itself, which, if accomplished, will mean the manufacture of oils from solid fuels. These processes are all equivalent to gasification systems since their object is to promote vaporization by suitable preliminary manufacture and thus fall into the same class as the coke oven, the blast furnace and the gas producer. At the present time the production of the gasoline fraction distilling under 300° F. is about 27,000,000 bbls. per year or 10.8% of the whole home production of crude, and substantially all of this is used for gasification, largely in engines, but also in lighting and heating appliances.

Gas producers have been, and, with the exception of the coke oven in large installations, will continue to be the basic apparatus for gasifying solid fuels. As such the gas producer must be regarded as an essential element of the gas power situ-

ation intimately associated with the status of the internal combustion engine. For the past ten years the journals and the professional society transactions have been full of reports on, and studies of the gas producer. Many expensive government investigations have been carried out and reports of conclusions published, and yet in spite of all this effort and publicity, progress has been slow when measured by the number of installations and amount of coal gasified in them. This at first is puzzling, in view of the repeated demonstrations that any sort of fuel is gasifiable chemically, and that almost any producer can gasify almost any fuel, but it is clear when the costs, reliability and quality of the gas are examined, and these things are too often ignored. Gas that constantly varies in quality or that is excessively dirty, loaded with tar or dust or lamp black, is not of suitable quality. Producers that cannot be operated for long periods of time without shut downs for cleaning and repairs, or that fail to make suitable gas any time and in normal quantity cannot be called reliable. Producers that are excessively big and heavy or that require constant poking and fussing to keep them working, and impose excessive fixed and operating labor charges on the gasification must be classed as expensive. Even those producers that can gasify cheaply and reliably but that require a selected fuel, obtainable in a given locality only at an excessive cost over another fuel more common, must for that district be classed as costly to operate.

The period just closing may be regarded as one culminating in a satisfactory fixed carbon gas producer from every standpoint, except in very small sizes, and as a period of realization of the fundamental difference in the problem of bituminous coal, lignite, and peat gasification but without an equally satisfactory solution. Analysis of the gas producer processes and structures will show clearly along what lines of thought the present satisfactory conclusion with the fixed carbon producer has been reached, and similarly, along what lines efforts are being directed to meet the problem of the small producer and that of gasifying the volatile coals.

A producer gas is primarily a mixture of the fuel volatile discharged by roasting, and of the fixed carbon gasified by steam and air reactions, with possibly some inter-reaction between the

products of distillation and either the fixed carbon itself or the fixed carbon gas. It is somewhat of a shock to discover that two such simple processes as roasting a fuel and blasting steam and air through a coke bed should either separately or combined give any trouble or involve any difficulty in making a structure suitable for their execution, yet such is the fact. In the first place, considering only the coke bed, regardless of the origin of the coke and independent of the roasting operation which produces the coke either in the producer or elsewhere, the fundamental condition to be fulfilled is a more or less even and homogeneous contact of the blast with the coke. Unless all the pieces of coke are equally swept by all the blast, some of the blast may pass through without reacting at all and burn some of the good gas, or only partly react, in which case the production of gas is below normal in quantity, the gas is bad in quality, and the ash carries much unused coal. Whether or not this condition will be fulfilled is primarily a question of structure, though partly one of manipulation, and it has taken a good many thousands of dollars and several years to realize this fact, simple as it sounds when stated.

In order that this uniform and general contact between blast and coke shall be maintained, there is required, first, a suitable introduction of the blast into the bed; second, a suitable escape of the gas from the bed; third, a coal bed uniform in thickness, size of lump and compactness; and fourth, no short circuits for the blast, through bed, or the brick lining, or between them. The natural tendency of the blast in passing through a bed that offers resistance to flow is to concentrate the flow along the path of least resistance, and then, by thus burning away the fuel that bounds that path, to further decrease the resistance and increase the concentration of the blast, accelerating the opposition to the even distribution that is so essential to the production of the proper amount and proper kind of gas. A coke bed retained between brick walls, whether they be straight or curved or vertical or inclined, involves a lesser resistance next to the walls than through the bed, simply because the coke lumps will pack more tightly against themselves than against a brick wall. Of course any leak between bricks or between lining and shell is a direct short circuit path.

If the entering blast has a direction and a velocity that tends to make it travel toward the outside wall, it will surely concentrate there and the center of the bed be comparatively inactive and cold. The blast should enter uniformly over the whole bed area or be directed away from the side walls. This requires for up-draft producers a grate bottom and not a solid bottom. It absolutely prohibits the use of central umbrella-top blast pipes such as have been in common use in the older types of gas producer designed for making metallurgical furnace gas. In down draft producers the blast naturally enters the entire top uniformly, as it should, but even here it might properly be restricted at the edges, which restriction, whether at the top or bottom, is accomplished by an inclination of side walls toward the center. For the up draft producer then the support of the bed on a grate with or without an inward tapering side wall may be regarded as one important structural conclusion naturally adapted to good gas making and the result of some years of experience. With respect to gas exit from bed the condition is somewhat similar. In up draft producers the influence of the outlet pipe location is negligible if there be a large free gas space above the bed, but this involves considerable waste of structural material and space, which can be avoided by a central discharge for the gas close to the bed, and which is quite as effective without the additional height. In no case can a side discharge close to the bed be permitted as it tends to concentrate blast flow along the walls. This is another simple conclusion that has cost time and money to reach.

Finally, as to the bed itself and its homogeneity, or the uniformity of its resistance to blast flow and the maintenance of a constant active depth, three conditions must be fulfilled. First, uniformity of rate of coal supply, commensurate with consumption; second, a correspondingly uniform rate of ash discharge equally from all over the bed bottom and not from sides or center alone, to maintain level the surface that separates ash from coal; and thirdly, some means of compacting the bed, which by its gasification tends naturally to shrink, promoting free spaces next the side walls and forming holes anywhere in its body. Uniform coal feed may be accomplished by mechanical feeding, equivalent to the stokers of boilers, dis-

charging the coal over the free top surface, or by the full hopper system, which seems to be even more satisfactory and simpler. The uniform discharge of ash can be accomplished only by a shaking form of grate and is almost hopeless by any of the old style, water sealed bottoms and mechanical ash plows. Such grates, however, must have definite provisions for clinker removal as clinkers are bound to form either occasionally or continuously, and so far the most satisfactory means of removing the clinker seems to be the maintenance of ample space between grate level and the side wall sills, to permit of the insertion of a hook or poker when the bottom of the producer is open. But the maintenance of the compactness of the bed to insure uniform resistance through it, closing up shrinkage holes, and pushing down clinker lumps, is still a mooted question. Present means range from the ordinary old style, hand poke bar, operated from the top, to various mechanical movements, ranging from the water cooled, power operated poker to the grinding and shearing action produced by rotating one part of the bed on another, which requires that an entire casing and part of the bed be roller supported and power rotated.

None of the various proposals for general direction of flow has proved so satisfactory as the simple up draft through-flow type, which may now be regarded as standard for anthracites and cokes. There is still some difference of opinion and practice as to mode of blasting and the pressure to be maintained, though the tendency seems to be, as it rationally should be, in the direction of suction operation, using positive blowers beyond the scrubbers as a means of moving the blast through the bed rather than the previous proposal, hailed with such delight on its arrival, that the piston of the gas engine be made to serve the purpose of a blower. A gas engine piston is the most expensive blower of suction type that can be designed considering the reduction of power that the low initial pressures cause. The rational solution of the suction operated producer, which with the blower system may and should supply pressure gas to pipe lines, rests on the two facts, first, that any leaks must be inward and not outward, thus conserving the life and health of operators on the one hand, and avoiding producer room explosions and fire on the other, and second, that in this way one producer plant

may feed any number of distributed engines or gas fires. The only harm that can come from inward air leaks lies in the direction of either burning gas that has been formed or causing an internal explosion in the gas system, neither of which can be regarded as dangerous. Such a suction operated system permits of the exposure of the ash bed whenever it is desirable for inspection of grates or removal of a clinker without stopping the gasifying operation, though to be sure, there will be some change in gas quality during this period through the entrance of room air instead of the humidified air blast.

Given a uniform coke bed condition as to depth, compactness and blast resistance, there is only one reason why the gas produced should not be uniform and steady at all loads, and that is a variation in the quality of the blast itself. It is clear that any change in the mixture content of the blast must be responsible for a change in the hydrogen content of the gas, and similarly, for a bed temperature change, which in turn will affect the ratio of carbon dioxide to carbon monoxide in the gas. The maintenance of uniform blast quality is, therefore, a most fundamentally important operating condition. It is rather surprising how long it took for producer builders to realize this fact and provide suitable appliances for insuring the desired constancy, but this is no more surprising than the slowness with which conclusions were reached as to the suitable structural conditions necessary to provide for proper bed conditions, blast entrance and gas exit. Naturally the first scheme to be put into operation, as is the case in any new industry, is a borrowed one, and in this case the steam jet blower of the metallurgical gas producer was used on the power gas producer. This blower is utterly incapable of delivering a constant ratio of air to steam at different steam pressures, against different bed resistances, and both steam pressure and bed resistances do vary in operation. Without going through all the intermediate stages of plans and methods and apparatus for proportioning steam to air and for making the steam, which latter was originally made in a separately fired steam boiler that often burned as much coal as the producer gasified, it is a fact that the simple and perfect principle of humidification to saturation at controlled temperatures, which has always been available, has

finally been utilized. There is ample waste heat in the gas produced to more than make all the steam that is required to keep the bed temperature properly low to avoid clinkers, and yet high enough to get good carbon monoxide and hydrogen content. It is also true that air humidified at temperatures ranging from 100° to 200° F. when saturated at any one temperature, will carry ample steam for the purpose and in accurately measured ratios to the air. Therefore, all that is required is the use of any one of the various simple forms of humidifiers for saturating air, heating the air or the water, or both, by the outgoing gas and provided with thermostatic control of the blast temperature, in order that, as saturated, it may be of constant water vapor content. Simple as this may be, and open to all as a common piece of apparatus and general engineering practice, it is surprising how few of the producer manufacturers have adopted it, and yet it is an unquestionably satisfactory conclusion. Reference need only be had to the ring top vaporizer and to the separate vaporizer of the now old suction producers, which never maintained the temperature anywhere near constant nor permitted the air to attain a constant degree of humidity and which were pushed so vigorously and designed and sold in such numbers in spite of their unsatisfactory character, to fully realize what this simple solution must mean to the producers of the future.

It is because of the adoption of apparatus embodying such principles as are outlined above and constructed of suitable materials of proper workmanship that we have today such satisfactory coke and anthracite producers; satisfactory, not, however, in all sizes and to only a limited degree as to price and weight or space occupied. A very small gas producer even with coke and even if constructed as above does not work properly because it does not keep hot enough. The producer bed of six inches diameter should yield a quantity of gas for which there is a large demand and which if available will permit small, independent, producer gas engine plants to compete with the now satisfactory and very numerous gasoline and oil engine installations. Apparently what is required, however, is some means of conserving the heat to oppose the natural tendency for dissipation through the side walls, which offer very much larger

surface in proportion to bed area than is the case with large producers. Whether improved insulation will suffice or whether preheating of blast in some manner not yet tried will be necessary is not at all clear. The question must be regarded as wide open to investigators and designers and a very attractive field exists in view of the prospects of adoption if success is attained.

In all cases the existing satisfactory coke and anthracite producer is excessive in weight and space occupied. It is this limitation that has prevented it from coming into general use at all for any sort of transportation service, and though some experimental installations have been made, the small number of them verifies the conclusion of unsuitability in this respect. With normal rates of gasification, ranging on the average in the neighborhood of 10 lbs. of coal per sq. ft. of bed cross-section, the explanation is clear. To reduce the size and weight requires higher rates of gasification and so far no satisfactory means have been found to accomplish this. There is a necessary low limit to the time of contact between the blast and the carbon to complete the reaction at any given temperature. Higher blast rates to gasify more coal per sq. ft. per hour will require, from present indications, corresponding thicker beds to maintain this time of contact, and this in turn will require higher blast pressures or greater blast suctions. There appears to be no fundamental reason why thicker beds should not be used but there is a somewhat serious objection from the point of view of the present structural standards to the use of higher suctions, and that is excessive leakage. Modification of the methods of construction by making tight shells will permit of the use of higher suctions, but will not limit the high blast power requirements incident thereto.

Most of the attention so far given to reduction of size or increase of capacity of producers has been directed by two ideas; one, the reduction of auxiliary equipment, such as scrubbers, and the other the change in the gasification method. With respect to the scrubber idea it seems rather absurd to retain a large and bulky cylindrical tower of coke that must be made strong enough to stand without injury an internal explosion, just to wash the dust out of the gas, and surely such a crude piece of equipment must soon be entirely superseded by small

and more nearly perfect mechanical appliances, based either on the line of the Thyssen beater form of mechanical washer, or on the high pressure filter idea of the Smith tar extractor or the Cottrell electric method. Whatever is done it is clear that the bulky coke tower must go just as surely as did the old and once standard gas holder. No one would think today of installing gas holders in connection with the power gas producer and so it will be with the coke scrubber tower before very long.

Modifications of method for the production of high rates of gasification have taken two lines of direction. First, the pulverized coal producer, and second, the slagging producer, operating either with pulverized coal or the ordinary bed. Unverified reports have been circulated, indicating that with the slagging action, modeled on the blast furnace, rates of gasification exceeding 100 lbs. per sq. ft. per hour have been obtained. The fundamental idea is that high rates mean large production of ash, and the necessary high temperature, a corresponding bad clinker formation, so that continuous operation should require a flux to slag the clinker and ash. So far no suitable flux has been found and results are unsatisfactory but interesting and promising as a new line of development. It has not been demonstrated that the addition of sufficient steam to the blast will not prevent the formation of excessive clinker and avoid any necessity for a flux. There is every reason to believe, on thermochemical grounds, that this is all the remedy for the clinkering that is necessary. At the same time it has been demonstrated that a satisfactory slag flux is not available, or rather that a flux that is suitable for one ash is entirely unsuitable for another. There seems to be some evidence, in addition, that the use of a flux will promote the formation of clinker in the intermediate stage of sintering before slagging takes place. The pulverized coal producer has entirely failed to support the promise of high rates of gasification and so far has indicated that the maintenance of a constant ratio of sufficiently and uniformly fine coal to blast is extremely difficult, if not impossible at the varying rates of feed necessary to meet ordinary load conditions. In this respect the powdered coal producer is similar to the oil gas producer, operated by an air-oil spray instead of an air-pulverized-coal

blast, each with or without steam. These two processes have a great deal in common and are exactly identical if the coal is infinitely fine, but different if it is not, inasmuch as coarse particles of coal dust do not quickly react but tend to carry through the chamber as sparks, and escape. Even with infinitely fine coal or with oil, the difficulties are material, due to the necessity for zones of definite chemical composition or reaction and of definite temperature, with which zones the currents of gas tend to interfere in spite of the introduction of baffles and separate chambers as mechanical assistors.

The fundamental differences between anthracites or cokes and the bituminous coals, lignites and peats aside from the coking tendency, which is a thing by itself, are found in the large amount of volatile in the one case and the almost zero quantity in the other and to some degree in structural strength of the cokes. This volatile for bituminous coal may be large in amount, upward of half the weight of combustible. It has a high calorific value, four or five times that of the gasified fixed carbon and practically all combustible. In the case of lignite and peat, the amount of volatile remains large but becomes decreasingly combustible and increasingly non-combustible, largely due to its water vapor and carbon dioxide contents. Eliminating then the coking and the packing tendency of some of the lignites and peats as physical properties, interfering in both cases with the passage of the blast, the fundamental difference in the system of handling must be directed toward the proper liberation and treatment of this volatile and its subsequent mixing with the gasified fixed carbon. Lack of progress can be traced directly to a lack of realization of the importance of a separation of treatment for the roasting or distillation stage from that for the subsequent gasification of the fixed carbon as a second stage. It is not surprising that having a producer successfully gasifying anthracite or coke, the same producer should be charged with bituminous coal or even lignite or peat. Any such producer will produce gas from these fuels, but not in a satisfactory way. It will either be characterized by excessive fluctuation of quality, excessive weakness or require excessive attention, excessive cleaning or fail to operate continuously.

Analyzing the difficulty, there appear to be two sub-problems; first, control of the ratio of discharge of the volatile to the rate of gasification of fixed carbon to maintain a constant ratio of these two constituent gases in the final gas; and second, control of the condensible or tar forming parts of that volatile to secure a clean gas. The rate of distillation of volatile depends upon the rate of heating and on the temperature in the green coal zone just as surely as in a coke oven or a coal gas retort. On the other hand the rate of gasification of fixed carbon is directly proportional to the amount of blast sent through the bed. If the gas is to be constant in quality then it is essential that the proportional content of volatile and of gasified fixed carbon, which together make up the gas, be constant, especially as the calorific power of the former is about five times that of the latter, and yet the prime factor controlling the rate formation of one is entirely independent of the similar factor for the other. At one limit there might be no volatile being produced at all if the green coal bed had been interrupted for a time and the blast through the bed continued. At this time the calorific power of the gas might be in the neighborhood of 120 B. t. u. per cu. ft. At the other limit the blast might be shut off to meet a no-load condition and at the same time a considerable body of green coal be left in the hot zone where, of course, it will continue to distil, yielding a straight coal gas of perhaps 650 B. t. u. per cu. ft. Between these two limits there will be some steady state possible if the apparatus permits it, at which the ratio of the gasified coke to coal volatile will be constant, and the first problem of volatile coal producer design is to provide a structure that will permit this. The second problem is to find a structure that will control the tar, either by converting it into a fixed gas or removing it as tar from the gas.

Most of the attempts that have been made to find this structure have been directed toward modifications of direction of flow in a single bed, coupled with control of coal fired, and as a result there are today on the market bituminous and lignite producers having the standard up draft characteristics of the coke and anthracite types, differing from them not at all or only in coal feed but with tar extractor added, and in

addition some new types embodying distinctly bituminous and lignite characteristics, and operating down draft, or double zone with part up and part down draft. Where efforts are made to control coal feed, they are all directed toward the idea of avoiding the maintenance of much green coal in the hot zone to limit the distillation after a reduction of the blast. There are two classes of means for this, one characterized by a hopper, kept continuously full, cold at one end and hot at the other, giving gradual distillation with feed, and the other a mechanical feed of coal in small amounts, somewhere proportional to load, directly into the hot zone with the idea that it shall distil as fast as supplied. Such devices applied to the ordinary up draft producer assist it in becoming and serving as a bituminous coal producer. Under these conditions the volatile is simply mixed at a temperature a little above 1000° F. with the gasified coke; the final gas has a maximum possible calorific power, which is the chief advantage of this type of construction, but it also carries over the maximum amount of tar or condensible volatile constituents, and requires, therefore, the most effective tar extractor to be complete. Such producers can, however, hardly be called bituminous producers because while reducing to some extent they do not prevent the fluctuation of ratio of volatile to gasified coke and they make the most tar to be later extracted.

This leaves as the only specially designed bituminous producers the straight down draft, the combined up and down draft or double zone, and the multiple independent chamber type. The first of these had led to the second, which has practically displaced it. Both, however, are characterized by down flow of blast through the distilling green coal, which burns as much of the volatile as can find air as fast as it distils. When the amount of volatile exceeds the air capacity to burn it, the excess, together with the products of combustion of the volatile that did burn, pass together through a hot coke zone. This reduces the burned volatile to carbon monoxide and hydrogen if the coke zone is hot enough, or leaves it carbon dioxide and water vapor if it is not, and at the same time fixes by decomposition all unburned volatile, with lamp black production if the zone is hot enough, or leaves it tarry if the zone is not. In the straight

down draft producer all the air passes through the distillation zone and, therefore, burns the maximum amount of volatile. All the products with any free blast pass through the entire coke bed, so the reduction of the products of combustion of the volatile is most complete and the fixation of the unburned volatile likewise. However, this results in the production of considerable lamp black, which is almost as objectionable as the tar itself, and requires that the producer bottom be kept closed so long as the producer is in operation. This prevents ash or clinker removal while running, and the high temperature of the gas bars the use of ordinary iron grates, which, under these circumstances, would burn out.

The double zone system is designed to avoid this particular difficulty and some desirable gasification characteristics are sacrificed to permit of continuous operation, and avoid the closed bottom and fire proof grate. In the double zone type the gas outlet, being placed at the center of a double height fuel bed, the bottom coke chamber, which is a straight up draft coke producer, may be constructed in accordance with the established good principles of standard up draft coke producers, including grate support, uniform blast entrance, shaking, clinker removal provisions and prompt opening for these without interruption of operation, and excepting only the gas outlet which must be near the side walls. Offsetting this structural advantage is a corresponding disadvantage from the gasification standpoint, which begins with the control of the ratio of the up draft to the downward parts of the blast. If all the blast is up draft this type is nothing more than an up draft producer with a hopper feed and side outlet for the gas and making tar; with the blast all down draft it is a pure down draft producer, necessarily intermittent in operation and making lamp black. The blast must, therefore, be divided and the accuracy of the division is of great importance. Blast division is directed toward the production of just so much coke in the top zone as can be gasified in the bottom zone and any departure means an interference in one direction or another. Even when the ratio of down draft to up draft blast is thus established, which is difficult, since it depends on the relative resistance offered by the two beds, the gasification action can-

not be entirely satisfactory. Practically all bituminous coals contain so much volatile that the proper fraction of total blast that may flow down through the top distillation zone, can burn only a little of it, and as a consequence some uncondensed volatile will be discharged and some unreduced products of combustion of the volatile that was burned, which means as a net result, a tarry gas of low calorific value. These producers can, however, work continuously for long periods because of their up draft bottoms and give fairly satisfactory gas from non-coking bituminous coals that yield strong enough coke and must, therefore, be regarded as commercial successes however employed.

This review shows clearly that the trend of progress along these lines is a sort of compromise between structure on the one hand and gasifying processes on the other. The gasifying process that would give ideal results, so far as present standards go, requires a structure yet undiscovered. The structure that would give proper service and operating conditions gives bad gas. This is undoubtedly typical of the youth of the problem and the two conflicting elements will be reconciled. There are no impossible elements in the problem, so it is only a question of time when the design of suitable apparatus will be found, adapted to the necessary process, just as well as to proper operating conditions and gas requirements. One illustration will serve to bring this home. The by-product coke oven is a reasonably perfect piece of equipment; it makes good, clean gas and good coke from caking coal, but it cannot be built small and be economical. Again, the blast furnace and the coke gas producer are both illustrations of reasonably perfect appliances for the gasification of coke. Therefore, it may be said that complete gasification of bituminous coal is today being carried out by the combined equipment of the by-product coke oven on the one hand and the blast furnace or coke gas producer on the other. The problem of designers is to combine the structural and process elements of these two sets of equipment in one, so that it will work in small sizes, as well as it does now in thousand ton plant capacities, and then, but not before, we will have a satisfactory bituminous producer. The adaptation to caking varieties of bituminous coal and to

those classes of lignite and peat which tend to bake in the bed and resist the gas flow is another and entirely independent step which by some fortunate chance may be combined with the above, but in all probability will require a separate treatment. At the present time, however, there is nothing in sight except a lot of proposals.

Finally, there is under consideration that gasifying plan which is really universal so far as fuel is concerned, involving more than one fuel chamber, the last of which contains coke. There is no reason why these should not be put into operation today for plants of large capacity, though, of course, they seem ill adapted to small units. The plan involves the primary distillation of any fuel, ranging from city garbage through wood, factory refuse, oils and greases, bituminous coals, lignites and peats, the complete burning of the volatile in any sort of fashion that is convenient, and then the passage of the products of combustion of this distillate through a coke bed maintained hot by the sensible heat of the primary fire, for reduction to carbon monoxide and hydrogen. In short, in accordance with this system there is required an equipment of two fundamental elements, one a common every day fire, and the other a coke bed, which may be operated up or down or double draft, as may be most convenient. The flue gases of a common boiler fire, metallurgical furnace, or even garbage destructor with or without extra air may be passed through the coke bed and the result will be a reasonably steady gas. From a practical standpoint such an equipment is bulky and normally requires a supply of coke, since it is only under rare and unusual conditions that the primary fire can be so controlled as to make an ample supply of coke for the second or reduction chamber.

Liquid fuels may be adequately prepared for use in internal combustion engines without gasification in producers and this is a direct advantage, but one that is more apparent than real, because the distillation process at the refinery is a manufacturing process that costs something equivalent to coal gasification. Gasification reactions must be exothermic in order that the necessary high temperature shall be attained and as a consequence there is suffered a sensible heat loss which be-

comes an operating charge against the process. This operating charge, equivalent to the fuel cost of the sensible heat lost in gasification, together with similar charges for labor and maintenance, when added to a fixed charge determined by first cost and life of the apparatus, do together make up the cost of fuel gasification as a fuel preparation process. Such expense is justified when the original fuel is cheap enough to yield a gas, that, with the added charges, can still compete with others, which is most likely if the gas is to be distributed through pipe lines, for here transportation costs are low compared with railroad and wagon. Liquid fuel offers advantages that are so different from, and so perfectly complementary to, those of gasification of solid fuel that it has developed in use along the very lines that have resisted adoption of gasification, more particularly transportation, though there is at present a well defined tendency to overlap. The gas producer has invaded the transportation field of liquid fuel where experimental installations have been made for some small and medium sized boats, and the liquid fuel engine working without gasification has invaded the stationary field, in all localities where liquid fuel is cheaper than coal, and in country districts even where it is more costly and where the size of the unit is too small for individual gas producers to work well and steam engines are uneconomical. Another case of overlap is found in the gasification of fuel oil for pipe line distribution where oil is cheaper than coal.

This brings out a most striking economical aspect of the liquid fuel situation, and that is the relation between manufacture of different grades from the crudes, and the characteristics of the engines to use them. It is undoubtedly true that liquid fuel engine development has been and surely will continue to be as intimately associated with oil refining as with the production of crude oil, for, other things being equal, the cheaper a given fuel or grade of fuel, the more effort can be economically expended in developing engines adapted to use it. Conversely, it is also true that once a great success is attained with an engine adapted to a given cheap grade of fuel, the increased demand for that fuel that naturally follows general adoption of the engine, will increase the cost of that grade

and at once stimulate effort in two directions; first, to create an equally satisfactory engine for another and cheaper grade; second, to create by improved fuel manufacture more of the demanded grade to supply the market, from other grades for which there is a lessened demand. Thus, the liquid fuel engine is in the long run quite as much a problem of adjustment to the art and economies of oil refining as of fuel thermochemistry and thermodynamics. This is the basis of the history of development so far, and as it must remain so for the future, it is important that the situation be clearly understood.

There were no liquid fuel engines until oil production and refining were established, just as there were no gas engines before the establishment of illuminating gas plants with their network of pipe lines in cities. Gasoline in the early days being a by-product of lamp oil manufacture and being easily vaporized with most simple apparatus, naturally received attention very early and this resulted in the modern gasoline engine now so generally and widely used as to have reversed the oil distillate market conditions. Gasoline has replaced lamp oil as the primary distillate of the refinery and has made the latter the by-product.

This gasoline engine development is due to the perfection of the carburetor for direct utilization of the fuel to make not merely a vapor but directly in one operation a suitable explosive mixture for immediate introduction into the engine. The wonderfully perfect system of world distribution of kerosene-lamp oil kept it constantly before everybody as a possible power fuel, and as a consequence stimulated another development, that of the kerosene engine, along quite different lines, so far as the fuel treatment is concerned, as the apparatus was incorporated in the engine structure, unlike the gasoline carburetor which is an attachment. Finally, toward the end of these two parallel developments is to be noted a third, that of the so-called heavy oil engine, based on the direct injection of the fuel oils as distinguished from vaporizable distillates and which the first and second class of engines could not handle at all. At the present time there is a clearly defined tendency to eliminate the second or middle class entirely, merging it partly into the first developed or carburetor system on the one

hand, and partly into the third and latest developed or injection system; the former characterized by external preparation of a suitable working mixture introduced during its suction stroke, and the latter by mixture formation directly in the working cylinder after compression.

There is every reason to believe that these two systems for the utilization of liquid fuel will become the standards of the future and that engines embodying each will be made available to an ever widening class of service. As between them they can utilize every possible class of liquid fuel and liquid fuel product satisfactorily, attention should be concentrated on their fundamental processes and apparatus characteristics.

The differences between the two systems, which may be called the carburetor system and the injection system, are now becoming well understood. The carburetor system makes mixtures externally and so is limited as to amount of compression possible before ignition to something less than one hundred pounds per square inch, except for alcohols, by the ignition temperatures of the mixtures, and, therefore, must be of limited thermal efficiency. Their maximum pressures are for the same reason also limited to fairly low values, rarely reaching four hundred pounds per square inch, and so they may be built reasonably light. The light weight type of engine will, therefore, be of the carburetor system and will have moderate or low thermal efficiency, but may be built as small as desired, or as large as corresponds to the maximum cylinder diameter allowable for any internal combustion engine. On the other hand the injection system cannot be built really small at all because of the difficulty of control of the minute individual injections. It is a more expensive construction and must, therefore, be limited to services that it can better perform than the carburetor class. As it suffers no limit as to compression, its efficiency may be very high, limited only by the correspondingly high maximum pressures, which determine the weight of all parts. The injection system is, therefore, especially adapted to larger sizes as it is essentially a heavy, expensive structure, but as economical of fuel as its builder may desire.

Of course, there will be exceptions to this double system of liquid fuel internal combustion engines represented by in-

dividual machines, or by small groups of one special type, just as there always have been, and each one that offers some useful feature of adaptability to a given service condition will stay and be reproduced, but nevertheless, the liquid fuel engines of the immediate future will in general belong to one of these two classes of systems, and development or perfection of the system will benefit every engine of the class, however unique it may be as to structural features.

Tracing first the growth of the ideas basic to mixture making from the light distillate, gasoline, it is not surprising to find the earlier efforts controlled by imitation rather than by bold departures along lines discoverable by an analysis of the problem. Analysis is rarely undertaken except as a conscious effort following a failure, and even then is apt to be superficial at first. If this were not the case we should not have had to wait for our commercial automobiles thirty years after the successful demonstrations of engine operating on gasoline vapor. It was gas lighting that prompted someone to blow air through or over gasoline, to get a combustible gas. To operate an engine on this gas after it had been operating on coal gas can scarcely be traced to any economic conviction that the world could use gasoline engines, or to any deep scientific conception of the physics of vaporization. The same can be said of the addition of wicks, or other means of increasing the gasoline evaporating surface to reduce the size of the apparatus for preparing the gasoline for use in a gas engine.

This borrowed scheme of surface evaporating carburetors did not and could not work well on any fuel having the physical properties of gasoline. Gasoline is a solution of many hydrocarbons in each other, each of which has a different vapor density, vapor pressure, boiling point, latent heat, specific heat of liquid and vapor and combining air ratio peculiar to itself. It is from such a solution that the carburetor must make a constant quality mixture of air and vapor in combining proportions. No process of vaporization by bubbling, surface or wick contact of air, passing through a gasoline chamber, can fail to fractionate the mass. It will also cool the mass, depositing water vapor carried by the air and by lowering the temperature and the vapor pressure, accentuate the fractionation. At

varying engine loads with corresponding variable time of contact of air and gasoline, the ratio of air to vapor will vary inversely as the air is thus humidified to different degrees. A fuel of simple chemical character, like alcohol or benzole, having a definite vapor pressure and the same for every part of it, can be successfully handled in such an appliance, provided heat be available to supply the latent heat of vaporization, and under control to automatically maintain a constant mixture temperature, and provided the contact always lasts long enough to saturate the air and is intimate enough to give a homogeneous mixture. However, with a fuel that fractionates, the case is hopeless, and to handle such requires a change of procedure directed primarily toward prevention of fractionation. This was provided by Daimler's engineer, Maybach, in the now standard process of isolating the fuel to be vaporized from the main fuel mass, so that all the fuel so isolated is completely vaporized in its air, and none left behind or returned. This principle of vaporization is just as soundly applicable to any of the other complex liquid fuel distillates, including kerosene and gas oil, though this fact is only now beginning to receive recognition.

Proportioning of air to fuel is a necessary accompanying step to the carburetion process and supplements the scheme of vaporization. The suction of the engine automatically creates the conditions for air flow, establishing a partial vacuum in the air passages, and as the rate of air flow to the engine is measured by this vacuum at any point of the intake passages, the same vacuum can be used to establish and control a proportionate flow of gasoline from a constant level source open to atmosphere, into the same air passages. Proportioning may thus be accomplished by the same means that effects the isolation of the fuel to be vaporized. The carburetion method thus developed consists of simultaneous flow from an atmospheric pressure source of both gasoline and air, each through passages of some definite flow resistance, to a region of partial vacuum maintained so by the engine suction and of vaporization of the fuel by contact of the separately metered streams, whether the flow be steady or intermittent and at whatever rate.

This standard system of carburetion was as originally worked out very imperfect, both in proportioning and vaporization. For twenty years designers have been occupied with improvements, largely directed toward improving the accuracy of the proportioning but recently also toward perfection of the vaporization, which may not be complete even though fractionation is prevented.

The increasing demands for gasoline have forced oil refiners to market constantly heavier grades of distillate, some of which sold today as gasoline are almost as heavy and as low in vapor pressure as was the kerosene of the early days of the lamp. As a result, the mixture formed by contact of this gasoline with air at atmospheric temperature, especially in winter, is not warm enough for the fuel to be completely vaporized. Such a mixture of air, vapor and liquid requires a supply of heat to dry it by raising its temperatures, or must be limited in use to an engine that can operate as well with wet as with dry mixtures. This latter condition of operation with wet mixtures applies to any single cylinder engine taking all the fuel and all the air through one inlet valve, on, or near which, further vaporization takes place by wall heat, supplemented by hot residue gas in the clearance space, and finally any remaining suspended liquid drops by the heat of compression itself. Even in this case, however, when the engine is operating on wet mixtures the result is not good. Some liquid will come in contact with the interior walls. All such liquid that touches hot walls will be carbonized and all that touches cool walls, wetted by lubricating oil, will be absorbed and spoil the lubrication. Multicylinder engines supplied from a single carburetor must have manifolds or headers to distribute the mixture to the several cylinders. In such cases it is almost impossible to give to each cylinder the same proportion of air and fuel when part of the fuel is in the liquid form, largely adhering to the pipe walls though partly suspended as fog.

The recognition that there was such a problem of distribution of wet mixture appeared first in the special designs of headers to replace the simple longitudinal pipe with lateral branches to each cylinder, by substituting the symmetrical form of manifold with long bends so that each branch path has the

same number of turns of equal radius and total length. Another evidence of the same thing is the air supply heater and the warm water jacket for the carburetor. These are makeshifts and not solutions of the problem. The end sought must be frankly met by providing for just so much heat as will warm the mixture to the point of drying it, which, with present gasolines, requires a mixture temperature close to 180° Fahr. Warm mixtures mean decreased density of charge and loss of power, and possibly reduced compression, but cold mixtures mean unvaporized fuel which may escape combustion, cause loss of efficiency, carbonize the interior of the combustion chamber or impair lubrication. For each engine there is undoubtedly some mixture temperature at which best combined results in power and efficiency will be obtained, but some sort of heat supply and temperature control is necessary today. This necessity is least in single cylinder engines and greatest with the greatest number of cylinders supplied from one carburetor.

Intimacy of contact has the greatest possible influence on the minimum temperature at which dry mixtures are obtainable, for a drop or pool of gasoline not swept by air must develop a vapor pressure equal to the pressure of the whole mixture, which is nearly one atmosphere. To develop a fuel vapor pressure of one atmosphere requires a very high temperature compared to that required to develop the proper partial vapor pressure in the mixture, which is approximately the same part of the whole pressure, as the volume of vapor is of the whole mixture volume, when air and fuel are in combining proportions. Introduction of the gasoline in fine spray form is mainly relied upon for this homogeneity of contact but finely divided sprays are difficult to make and it is only now being recognized by studies in glass that most of the so-called spray nozzles, spatter plates, and screens are not what they were thought to be. Improvements in spraying and homogeneous mingling of fine fuel fog and air are equivalent in effect to a material reduction of the dry mixture temperature, and in proportion as this is recognized so will progress be fast, especially when associated with corresponding improvements in heat supply and mixture temperature control.

These ideas of the importance of mixture quality and its

separate control by means independent of proportioning are recent, as is also the recognition that when once perfectly worked out, the same means for making correct dry mixtures are equally adaptable to any liquid fuel whatever, including alcohol and benzole, as well as kerosene, solar and gas oil and even some crudes by no other difference than that of temperature of mixture. All those fuels that yield mixtures of proper quality at suitably low initial temperature, will undoubtedly be used in the same handy, cheap engine that has been developed for gasoline. Fuels that require mixture drying temperatures so high as to seriously reduce horsepower or increase weight per horsepower, by the temperature effect on charge density and allowable compressions, will be left for use in the more expensive class of injection engine.

It is with proportioning that most carburetor designers have been occupied rather than with mixture drying, and the solution of proportioning is beginning to emerge from the invention to the design stage. The vacuum flow principle is the accepted one, but its application must be based on the physical laws of flow of air and gasoline through their respective passages and orifices for all vacuums. It is only in recent years that anybody has taken the trouble to experimentally determine these laws of flow to establish data for the design of what might be called similar orifices or passages for the flow of air and gasoline; similar by reason of similar laws, or failing to find such similar passages, to determine the amount and kind of auxiliary compensation to be introduced. No matter what the form of air passage or type of air flow, whether hole in plate, short tube, Venturi tube, long pipe, or bend, and of gasoline passage or type of gasoline flow tube, whether slot, hole in plate, nozzle, or capillary, single or in multiple, it seems that, once set to give the desired proportions for starting, the gasoline flow will increase faster than the air for increased flow rates induced by higher vacuums, characteristic of high engine loads or speeds, and the mixture becomes over rich.

Originally the only correction attempted was compensation by an auxiliary hand control valve beyond the mixing point, which, on opening, introduced more air without a corresponding increase of vacuum at the gasoline jet chamber, and affected

proportions correspondingly. Replacement of this hand control auxiliary air admission valve by a spring closed check valve was regarded as a great advance, indicated by the name generally applied to carburetors so fitted as "automatic" carburetors. The single automatic auxiliary air check valve quite failed in its purpose because the distortion law of the spring became the determining factor. To be sure, engines ran better than before but not as they should, especially on automobiles where the service is most severe in view of the wide range of speeds and loads and their sudden change, incident to regular operation. While not of itself an adequate corrective influence the auxiliary air valve did serve to call attention to the problem, to the possibility of corrective influence under automatic control on the one hand and on the other to the desirability of originally correct primary control. It is along these two independent but related lines that the progress of the day is proceeding, guided by ever more exact studies of flow laws and proportionality, so it may be fairly said that while the solution is either not yet found, or if it exists somewhere, is not yet generally adopted, it is not far off, and true automatic correct proportioning will soon be an accomplished fact.

There have been some serious disturbing influences at work retarding the desired solution of the carburetor problem of accurate proportioning and complete vaporization, and some of these undoubtedly will continue to exist, though a clear understanding of the situation should make them cease to be obstructions. The first and most fundamental of these is concerned with the definition of correct proportioning itself or with what should constitute the ideal of proportioning. On chemical and thermodynamic grounds it would seem that maximum power, coupled with maximum efficiency, requires a homogeneous mixture of combustible and air in combining proportions, the fuel thoroughly vaporized and diluted as little as possible with neutral products. This leads to ideas that the ratio of fuel to air should be constant, regardless of speed and load. Excess fuel is unburnable, and causes a direct loss of efficiency and power. Excess air being a neutral diluent is a power though not an efficiency loss. It is undoubtedly true that in most engines maximum power is obtainable only with excess fuel in

the mixture over the combining ratio; it is also true that most, if not all, gasoline engines must have the carburetor adjusted to give an excess of fuel at closed throttle positions; and so it is not surprising to find a prevalent opinion that constant ratio mixtures are not desirable, and that combining proportions are unsuitable either for full or closed throttle. Unfortunately for progress, those holding this view are not able to formulate requirements as definitely as is necessary for design, nor are there available any fundamental data to support the contentions of the variable quality advocates. On the other hand there is a simple explanation for these observations and this points to different and removable causes, so that there seems to be no doubt of the soundness of view that the correct mixture is one of constant ratio of air to fuel, and that is the combining proportion. That maximum power corresponds to fuel excess is rationally explainable by non-homogeneousness of the mixture or incompleteness of the vaporization; more thorough stirring and mixing and a suitable rise of mixture temperature should and will change the result. Similarly, at closed throttle there is between throttle and inlet valve a considerable vacuum, more than half an atmosphere being not uncommon, so that if there be any leaks in the pipe joints or around the inlet valve stems, it is clear that there will be a constant flow of air into the mixture along these leak paths, and the fuel per unit of air passing the carburetor must be greater the larger the fraction of total air that enters through leaks and the less the air that enters where it should, through the carburetor. The remedy is clearly to stop the leaks, and in the case of valve stems this means some sort of packing and certainly not a carburetor designed to give variable mixture to compensate for unknown and changing by-pass leakage.

An illustration of influences that have retarded progress in carburetor design is the tendency to judge goodness by starting characteristics, especially of automobile or boat engines. Any operator will promptly condemn a carburetor that does not permit a prompt start or steady idling, however well it might work under load, and just as many will endorse one that gives most variable proportions under load, if its starting and idling conditions are good. The progress retarding effect of

this is especially marked in those carburetors that are really two in one, one of fixed setting and proportions for starting and idling, and the other brought into play with opening of the throttle which also cuts off the first, because such carburetors may seem to work splendidly from superficial observation and yet be really very bad actually.

Still another bad influence can be traced to a tendency to accept conclusions from one type engine and apply them to another, or to adopt a course of procedure for one case dictated by success in another, on an assumption that they are identical when they are essentially different. There are several types of engine or service where the carburetor requirement is most easy as to proportioning, and where success is possible with apparatus quite unsuited for the general service. This general service condition is that of variable flow rates through the carburetor due to regulation by throttles, and fundamentally distinguishes it from the easy case of constant flow rates even though intermittent. This constant flow rate condition is typical of the hit-and-miss governed engine, the most widely used type for stationary and tractor service, and which, whenever it receives a charge at all, takes the same charge and at the same rate through the carburetor. The same flow condition is found also in the boat engine which normally drives a screw propeller at constant speed and constant load. For this condition of constant flow rate any form of air or gasoline orifice is about as good as another, and all that is required is a valve to get the single adjustment of operating ratio for which there is a starting and a running setting. The common names of mixers, mixing valve and generator valves, sufficiently indicate the simplicity that succeeds. Many wrong ideals and carburetion in engines on the market can be directly traced to the above sources. Success of such a mixer on an approved engine has led to its application on variable load or speed engines with bad results, correction for which is sought by cut and try mechanical ingenuity, exemplified by weird combinations of many tubes, orifices, valves, fans, screens, springs and diaphragms, having no relation, whatever, to the physics of flow and constancy of proportion.

At no time in the past ten years has there been any lack

of effort to solve the problem of automatic proportioning in constant ratio, but until recently this effort was largely unintelligent, but now that these laws of flow are being studied more and more, designers are extending them, and making rational efforts to incorporate in simple reliable mechanism such laws as have been established. It may be said, therefore, that the period of intelligent effort along scientific lines has arrived, and that there is within sight, though not yet attained, a rational solution of this automatic maintenance of constant ratio of air to gasoline, so essential to any problem of carburetion.

As a rule those designers that are concerning themselves with proportioning are not giving adequate attention to vapor pressures, vaporization and mixing, processes just as essential to proper carburetion as proportioning, and which when thoroughly understood, will make the same type construction of carburetor equally well adapted to any distillate fuel by a simple change of the temperature maintained to develop the necessary vapor, characteristic of that fuel. Some of the surprisingly numerous lines being followed for developing a mechanism capable of insuring constancy of proportion are extremely interesting. Nothing would be more worth while or of greater interest than to review these, but lack of space makes it necessary to note simply the three general divisions: one seeking to maintain the proportions through constant area of air and fuel openings by proper control of flow resistances and the effective heads, while the other seeks to control the variation of the area of openings, either one or both, without affecting the effective head, and as might naturally be expected, the third undertakes combinations of these two.

Mixture making from heavier fuels than the gasoline has developed along entirely different lines, some of which are destined to be retained, others to be abandoned. The effort was first directed along what must now be regarded as improper lines, though reasonably satisfactory engines were produced in great numbers and are still being built. Undoubtedly the original idea underlying the operation of these so-called oil engines, the development of which began immediately after the establishment of the world market for kerosene oil, is based upon the vague notion that this material required a great deal of heating

to permit it to be used. It could not form an explosive mixture by any of the bubbling or contact types of carburetors then in use for gasoline so it was clear that heat had to be applied, and in seeking for a means and a conception of the degree necessary, undoubtedly early efforts were directed toward boiling it. Boiling in a retort may continue to yield vapor up to 900° F., and yet leave an unvaporized portion. This sort of boiling not only fractionates the oil, but what is worse, is a destructive distillation, in as much as it makes residue not originally present but which was formed by overheating. The fact that the oil could be not entirely vaporized under a red heat led to the incorporation in the engine of red hot plates, tubes and bulbs, of all sorts of shapes, as means for securing a vaporization. These all fail to recognize that vaporization of these oils at such temperatures in their own atmosphere would destructively distil them and prevent, instead of produce, the complete vaporization that is required by engines. Out of all this sort of reasoning grew the so-called oil engine yielding a smelly, smoky exhaust, collecting carbon internally, limited to low mean effective pressures and, therefore, both inefficient and heavy.

The high temperature of the vaporizer that also serves as igniter is usually obtained by leaving unjacketed a portion of the combustion chamber wall, and as this is so often in the form of a bulb it led to the name of hot bulb engine, though it matters but little whether that so-called bulb is a tube, a flat plate, or any other shape. Such parts depend for their heat on contact with the exploding charge and are, therefore, sure to be too cool at light loads, or too hot at full loads for best results, and external lamps are common adjuncts. The quantity of oil is invariably controlled by a pump having a by-pass or variable stroke, a means feasible only with those fuels of low vapor pressure and not adapted at all to the higher vapor pressures of gasoline, especially in warm places and at high speeds. The oil being delivered to the vaporizer long enough before the end of compression to allow time for vaporization, limits the amount of compression to a low value to avoid pre-ignition; therefore, the efficiency is low and the mean effective pressure as well. Rarely is there even an approach to homogeneity of mixture at the

time of explosion, a sufficient reason for both carbonization and small power capacity.

It is truly surprising what a large number of engines and what a vast variation in the details of structure were produced under this development, which is primarily English. The most prominent engine of this class, in numbers sold and world distribution, is undoubtedly the Hornsby-Akroyd, the characteristics of which are now pretty well known everywhere as well as its limitations. The fundamental difficulties and limitations of this type are to be found in the facts, first, that vaporization is accomplished by contact of the oil with self-heating metal parts; second, that vaporization takes place in its own vapor, which requires that the oil be heated to such a temperature as will produce a vapor pressure equal to the total pressure, which is one atmosphere if vaporization takes place during suction, or something greater than atmosphere for any that takes place during compression. This invariably results in overheating the oil to a point where it carbonizes. Third, the presence of oil and air together during compression seriously limits the compression to such a low value as produces ignition at the end of compression where it touches the vaporizer-igniter. Finally the mixture is not and cannot be homogeneous: at one extreme point there is pure air and no fuel, while at another all fuel and no air. Nevertheless, these engines have proved to be easy to handle, wonderfully reliable and fool-proof and long in life though requiring frequent cleaning, but somewhat heavy and inefficient.

Material advance began with the conscious effort to reduce the temperature necessary to complete the vaporization and this follows the more completely the vapor is swept away from the liquid surface, as it forms, by the air that is to burn it, that is, the more air mixing there is at the time and place of vaporizing. In accordance with this idea vaporization must be accomplished simultaneously with air mixing and the place of vaporization must be a spot swept by air, or an air zone swept by the minute oil particles. When this is carried to the limit with distillate fuels there is no destruction or carbonization, because vaporization will be accomplished at a temperature lower than that at which the distillate was formed in the still where it was

produced, and the resulting mixture approaches the homogeneous. This is the carburetion method and may be carried out externally to the cylinder or directly within it. This principle of vaporization and mixture making when externally executed in these oil engines will undoubtedly lead in time to a form of oil engine substantially identical with the existing standard gasoline engines, and all that is necessary is to adapt their carbureting vaporizers to the required temperature, which is about 300° F. Such conversion will replace some of the old vaporizer forms of oil engines, and it is interesting to note that the first substantial step in this direction has been accomplished in the conversion of the gasoline tractor to kerosene.

As has been indicated above, one way of accomplishing the vaporization at a minimum temperature without residue, and simultaneously accomplishing the mixture-making function is to scatter the oil through a charge of air by spraying that oil into the air in the cylinder after compression. This is the other logical outcome of the old vaporizer type oil engine and is exemplified today in two well known forms; one, the Diesel, exemplifies the principle better than the other, which latter has no name except the inaccurate recent one of Semi-Diesel, one good example of which is the Franchetti. The fundamental element of this injection system is the spraying of the oil into the air, in the clearance space and after compression, which permits of the use of a degree of compression as high as desired, without any limitation of ignition temperature. Injection of oil toward the end of compression is a logical development of the old hot bulb engine, but as applied to produce superior results the injection must be delayed until the compression is substantially completed. This limits the time for the oil injection to a fraction of a second, which involves very great mechanical difficulties of pump and nozzle construction, to get the minute, accurately measured amount of oil into the cylinder in the very small time available, and in true spray form. In fact the time is so small that no such scheme of injection can possibly work on high speed engines but must be confined to low speed engines.

The injection of a solid stream of oil by direct action of a pump plunger is not only difficult mechanically but rather

fruitless because the object is not merely to get the oil in but to scatter it as uniformly and homogeneously as possible through the mass of air compressed in the clearance space. No direct injection of a solid stream can accomplish it alone. Therefore, a modification of plan has been worked out which involves the use of compressed air at a sufficient excess pressure over the compression pressure, discharging through the injector nozzle with the oil through suitably formed orifices to give both the speed and the scattering action required. The spraying is more perfect, the less viscous the oil, and as viscosity is largely a question of temperature with any oil, preheating facilitates the desired action. It may, therefore, be said that the fundamentals of the sort of injection that is required are injection, with suitably high excess pressure compressed air, of warm oil into a clearance space where the air has been compressed previously as much as seems desirable. With oil drops sufficiently fine, due to good spraying action, there is substantially instantaneous vaporizing if the temperature of the air is high enough with reference to the vapor pressure of the oil, which, it must be remembered, need only be something between five and ten per cent of the air pressure. Oil vapor pressures and air temperatures and pressures may be such as to make it impossible to vaporize the oil, but liquid oil in sufficiently fine fog or spray does not differ substantially from the vapor so far as its combustion is concerned. Such spray mixtures will burn exactly the same as vapor mixtures, so that a suitable injection will give good combustion conditions whether the liquid is vaporized or remains liquid, and, therefore, is just as well adapted to a very heavy oil that will not vaporize as to a lighter one that will. In this way the modern compressed air type of injection oil engine has been made capable of using any grade of oil that can be properly injected and is limited only by the ability of the designer to make an injection nozzle of suitable form to properly scatter the oil through the desired space and in a sufficiently subdivided state. At the present time there are some grades of oil for which existing nozzles are not well adapted but there is no reason to believe that suitable nozzles will not be found capable of handling any oil.

Such fine and scattering sprays in the presence of air may

burn in either one of two ways. If the air into which they are injected is above the ignition temperature, made so by compression alone or otherwise, or if there be an igniter adjacent to the injector, whether of the hot metal form or of the electric spark form, then the fuel will burn as it enters and give what may be called a non-explosive combustion, though perhaps improperly so. On the other hand, if the same spray mixture be injected into air that is not hot enough to ignite it, the spray may pass across the combustion chamber and be diffused throughout the charge of air without combustion. Then by contact with an igniter at the opposite side or most distant point, ignition will produce a true explosion of the whole mass. The former mode of action is characteristic of the Diesel engine; the latter of the Franchetti, and structurally they differ essentially in the relation of the igniting element to the injection element. In the Diesel the igniting element is located so that ignition occurs as the fuel enters from the injector. In the Franchetti the ignition is delayed until the fuel has all entered.

Substantially the same form of spray nozzle will be equally well adapted to one as to the other, though for the best working of each a substantial difference should be introduced, and is. Thus, in the case of the Diesel, as the compression is relied upon to produce an ignition temperature in the air, and as the clearance air is the igniter and the compression very high, it is not desired to increase the pressure any further in order to avoid the necessity for a corresponding increased weight of cylinder and running parts. This requires an adjustment of rate of injection to the piston speed and is normally accomplished by the resistance in the injection nozzle. If this resistance be enough, oil of given viscosity can enter only at a rate limited by this resistance, and the graduation of the injection is greater the more the resistance. Slow and controlled injection then is desirable under the Diesel system. On the other hand, with the other system there is no graduation required or desired. The sooner the oil gets in the better; therefore, the less the resistance of the injection nozzle the better,—consistent, of course, with complete atomization. While the same spray nozzle might be made to serve both, it is desirable that the Diesel be equipped with what might be called a resisting nozzle

and the other with a non-resisting nozzle, the former graduating injection and the latter permitting instantaneous introduction. Functionally the difference between the two is not that compression alone produces ignition in one where an igniter is required by the other, which is made the basis of the names Diesel and Semi-Diesel, but rather in the rate of injection, and the combustion without rise of pressure in the former and explosively in the latter.

Beginning with the old oil engines, then, with their hot metal vaporizing and igniting parts, an active period of twenty-five years of oil engine building is closing with three clearly defined natural tendencies in form or type of oil engines.

Vaporizing in air and mixing at the same time outside of the engine, as a principle, is leading the oil engine to the gasoline form, just as it is leading the gasoline engine to become an oil engine. This first class of oil engines, using in the heated carburetor only distillate fuels but of any density and any boiling point, will be limited in compression by the initial mixture temperature and by the ignition temperature, to low or moderate efficiency and mean effective pressure. They can be run at any speed, but are especially adapted to high speeds, and can be constructed in any size, but especially adapted to small engines of light weight.

The second emergent type is really the residue of the old vaporizer hot bulb oil engine. It is limited to low compression, will always be more or less foul, adapted to practically any grade of oil, with, of course, increasing deposits from the heavier grades and more frequent cleaning, not adapted to the very small size, or the high speed class, nor to the very large units, but confined to the intermediate sizes of moderate speed where simplicity of mechanism is more important than efficiency or light weight.

The third emergent type includes that now commonly known as Diesel, some of the so-called Semi-Diesel and the Franchetti classes. The type is characterized by direct injection of the fuel, preferably in fine spray form, after compression is completed, injection, spreading, and mixture making being more or less simultaneously accomplished and assisted by compressed air entering with the oil; ignition being accomplished in any

way, ranging from the temperature produced by compressing the air alone, to a hot plate, or electric spark, located anywhere, from immediately adjacent to the injector, to most distantly removed therefrom. This type is especially adapted to large sizes and to low moderate speeds, the size being limited only by structural strength or life of cylinders or the pressure parts. This class will always be heavy though capable of high mean effective pressures by reason of high compression. The efficiency can be made as high or the fuel consumption as low as desired since the compression is absolutely under control. High efficiency means high cylinder pressures and heavy parts, so in this type, weight of parts or weight of whole engine is to be balanced against fuel consumption. The thermodynamic cycle involved is not necessarily the same for all and ranges from the Franchetti, working on a true Otto cycle on the one hand, to the Diesel, which is a curtailed expansion of the Brayton, on the other hand, the relation of which is pretty accurately given as follows. Equal efficiencies and fuel consumption are obtainable from the Franchetti with about one-half the compression required by the Diesel with substantially equal working maximum pressure in both. The working maximum for the Franchetti is the actual maximum, but the working maximum in the Diesel is about half the accidentally possible maximum which would occur with excessively rapid injection or delayed ignition. For equal maximum metal stresses and bearing loads the latter must be built heavier than the former, enough heavier to carry nearly twice the emergency pressures when the compressions in each are such as to give equal efficiency, which in practice is approximately a little less than ½ lb. of oil per brake horsepower hour.

Overlapping of the field indicated above for the three emergent types of internal combustion liquid-fuel engines is to be expected, but consolidation is not likely. There is no sign that there will ever be a universal liquid fuel engine.

Engine design itself, even after the internal combustion engine had been established as commercial, failed to develop for a considerable time, during which practically only one type was built, and that in a very limited number of small sizes. The largest in 1880 was 20 h.p. This old original was a hori-

zontal single cylinder four cycle form and as designed noisy in operation, of only moderate compression, very large and heavy per horsepower, and entirely confined to illuminating gas mains for fuel. Today these engines are being built in great diversity of form and detail to adapt them to specific service requirements, and ten thousand different designs would be a conservative estimate. They are being built and manufactured in larger numbers than any other prime mover at constantly lessening, though still not low enough cost, in sizes from 1 h.p. to 5000 h.p., in speeds from 40 or 50 r.p.m. to over 2000 r.p.m., in numbers of cylinders from one to eight or even twelve, operating on constant pressure and constant volume internal combustion principles, with both the two and four cycle mechanism, cylinders and pistons both single and double acting. This is the result of a period of active design, which, in addition to developing a group of typical forms and arrangements of each group of structural elements for executing the various respective engine functions, has also resulted in establishing pretty definite types of engines, each adapted to some one service condition. Engine design today is definitely characterized by strong tendency toward greater diversity of type form for better adaption to new service conditions and by a corresponding trend toward standardization of details for each type. Design of any one type ranges between two extreme limits, one the result of an effort to get long life, independent of first cost, and the other disregarding life, seeks minimum first cost; the former, an expensive, the latter a cheap style; the former for long, hard service, the latter for shorter or intermittent service. Internal combustion engine design is, therefore, proceeding along lines of evolution as has the steam engine. After over two hundred years of steam engine design there are today more different forms of steam engine than ever before, and while each class tends toward standardization of its detail parts, there is no tendency for one class to conform to the other, quite the contrary. It may, therefore, be expected that in the future there will be greater diversity of gas engines in typical arrangements or type constructions, but a greater and greater adherence to characteristically good details of construction applied to them all, or in type groups.

Motor cycle engines, now the smallest class in size, are all vertical single acting, are all four cycle, all air cooled; excepting minor details they differ only in number or arrangement of cylinders, including the single cylinder, two cylinders set "V" with one crank and the four cylinder, four crank styles with angles of 0° and 180°, the former for balance. They are all high speed to minimize the weight, and surprisingly reliable in their main parts, though cheap, because low cost is due to manufacturing methods, not bad design. Such interruptions as occur are due mainly to ignition and carburetion equipment or valves, rather than to failure of what is more properly the engine itself.

The automobile engine, next in order, ranges in size from hardly more than a motor cycle engine as a minimum to upward of 100 h.p., and is always a multi-cylinder single acting engine today, with a tendency toward an increasing number of cylinders. The single cylinder style formerly built has passed away, largely because of poor balance and flywheel weight. The two cylinder horizontal opposed is still retained but to a small degree, as its balance and weight are within reason, but not so good as with more cylinders. Three cylinders are unknown; four cylinders parallel most common; six in line next in order, and there finally has appeared, apparently to stay, the eight cylinder "V"-type, consisting of two sets of four in line at angles of 45° or 90° with four crank pins, all in the interest of balance at first and turning effort later. Of American automobile engines now being built 50.3% have four cylinders; 49.1% six, and 0.6% eight. These cylinders, formerly cast in one piece with their heads and jackets are beginning to conform to stationary practice, and now 30.6% have separate heads while 69.4% are still cast with heads integral. The cylinders themselves are cast single, in 6.1% of the fours, and 2.5% of the sixes; in pairs, in 23.5% of the fours, 30.4% of the sixes; in threes, in 26.6% of the sixes; *en bloc* or one piece, in 70.4% of the fours and 40.5% of the sixes. Where formerly each crank had a bearing on each side, now a variety of arrangements are used; of the four cylinder engines 22.2% use two bearings, 67% use three, and only 11% use five; of the six cylinder engines, 44% use three bearings, 37% use four and

19% use seven bearings. Formerly all used poppet valves but recently sleeve, rotary and piston valves have appeared and are used in 4.9% of the engines. Poppet valves, the present standard form, are located 5% in the heads, 19.2% on opposite sides and 71% on the same side, the tendency being to avoid two cam shafts and to minimize valve gear. Most of them use purchased carburetors and ignition equipment, and the latter has materially changed in system since electric starting generators, motors and storage batteries became standard equipment. Where a year ago 87.3% used magnetos, alone or with batteries, dry or storage, this is now reduced to 59.5%, of which only 12.7% use magnetos only; a clear indication of a tendency to eliminate this auxiliary. On the other hand while a year ago only 11.9% used D.C. generators alone with batteries, this has increased to 37.9%, and dependence on batteries alone, the original standard, has almost entirely disappeared. The high speed makes make-and-break ignition apparatus difficult to design and this, coupled with the fact that jump spark can be purchased complete from special manufacturers, is responsible for an almost univesral use of the latter. With the exception of the few horizontal two cylinder opposed and the increasing number of the inclined "V"-type, all automobile engines are vertical. All are high speed and all now four cycle, the two cycle having been tried and rejected. With the exception of practically only one make, all automobile engines are water cooled. The enormous number in which they are made has made possible great perfection in construction at low cost through a true manufacturing system of economical and accurate production, using new materials and shop methods. As to methods, progress has been greatest in the foundry, where castings of a quality never before dreamed of as possible are now made in great quantities daily. In the machine shop many special tools have been perfected and new systems of assembly and inspection created. As to materials, it may truly be said that the general introduction of the alloy steels of high tensile strength and great toughness in all branches of shop practice is due to this automobile engine development.

Aero engines for aeroplanes, hydro-aeroplanes or dirigibles have become a class in themselves, chiefly characterized by

light weight, without which controlled air flight is impossible. In type form these are partly similar to the automobile engine of four or six water cooled cylinders in line, and the eight or twelve cylinders "V", but in addition there must be noted the distinctly aero engine of many revolving cylinders with one crank, and air cooled. The first Wright engine was modeled directly on the automobile style but redesigned for weight, which was brought down to seven pounds per h.p. In later designs of four and six parallel and eight "V" cylinders, this weight has been brought down to about 4 pounds per h.p. The lightest of all is the revolving cylinder type weighing 2½ pounds in large and 3 pounds per h.p. in small sizes, which, however, is closely approached by an English twelve cylinder "V" weighing 2.9 lbs. per h.p. in a size of 225 h.p. The speed of these engines is high, from 1200 r.p.m. for revolving cylinders and some auto styles up to 2000 r.p.m. maximum for the latter. High thermal efficiency is just as important for this class as weight, as tank and fuel weights must be carried and here the auto type is best, giving its power on ½ pound of gasoline per b.h.p. hour, the revolving type using appreciably more because of air resistance, opposing cylinder rotation. Reliability is being sought by increasing bearings, doubling of valves and ignition equipment, increased use of alloy steels and last, but most important, by installing double or triple engines, any one large enough to develop enough propulsive effort to insure safety of aeroplanes.

Motor boat engines range from the one horsepower single cylinder engine, through larger single cylinders and then through multi-cylinder grouping to get larger capacity, up to 1000 h.p. per cylinder and 6000 h.p. in six, which latter operate on the Diesel system. The smaller ones are now divisible into three groups according to speed, first under 500 r.p.m., second 500-800 r.p.m. and third over 800 r.p.m. Marine engines are all vertical necessarily, except for the detachable kind used on rowboats, are all water cooled but unlike the previously described classes are to a considerable extent two cycle though undoubtedly the four cycle predominates. While in some instances the automobile type has been borrowed bodily and installed in boats, this cannot be regarded as the normal American type of boat engine,

which is of heavier construction to adapt it to operating normally at full load for any length of time. This continuous long time full load service distinguishes the boat from the automobile engine, and which latter rarely has full load imposed upon it, and then only for a short time, and from the aero which while running always carries full load but which does not run as long as a boat. It is this same condition of normally operating at full load at constant speed that makes the two cycle engine a feasible proposition for boats; its defects of irregular operation, miss fire and back fire become noticeable at closed throttle for maneuvering or at low speed when operated on carburetors, otherwise it would be more widely used than it is. Absence of this low load irregularity in injection oil engines is responsible for a wider use of two cycle engines in this class than of four. Economy of small boat engines is not of very great importance compared to handiness and reliability, and this again favors the two cycle as does also weight per horsepower.

The really typical thing about these motor boat engines is the large variety of sizes, speeds and number of cylinders now on the market and the large number of different makes. According to a recent analysis by Motor Boating there are now built standard and offered for sale 1571 different sizes and styles of engines, both two and four cycle, ranging in size from 1 h.p. to 800 h.p. while larger sizes are built on order. Of these, 662 are two cycle and 900 four cycle. Cylinder sizes range from 3″ x 3″ to 16″ x 30″, and numbers of cylinders 1, 2, 3, 4, 6, 8, 9 and 12. Single cylinder two-cycle engine sizes range from 1-25 h.p. low, 1¼-12 h.p. medium and 1½-15 h.p. high speeds; two cylinder 4-400 h.p. low, 3-35 h.p. medium and 1½-25 high speed; three cylinder, 10-85 h.p. low, 5-36 h.p. medium, 6-45 h.p. high speed; four cylinder 20-800 h.p. low, 4-45 h.p. medium, 12-150 h.p. high speed, with larger numbers of cylinders only in the high speed class. The speed classes are 0-500 r.p.m. low, 501-800 r.p.m. medium, and over 800 r.p.m. high. Similarly, for four cycle engine the cylinder numbers and capacities are: for one cylinder 2½-12½ h.p. low, 2-10 h.p. medium, 1½ to 10 h.p. high; two cylinders 4-65 h.p. low, 6-30 h.p. medium, 4-30 h.p. high; three cylinders 9-150 h.p. low, no medium, 6-45 h.p. high; four cylinders the most common, 10-240 h.p. low, 10-122

h.p. medium, 9-100 h.p. high; six cylinders 25-360 h.p. low, 7½-200 h.p. medium, 18-160 h.p. high; eight cylinders 100-160 h.p. low, 75-225 h.p. medium and 50-200 h.p. high.

This shows clearly not only the wide variety but the tendency to build larger powers in larger numbers of cylinders, prompted by more uniform turning effort, better balance and, by no means least, great reduction of trouble that comes with large bores. As weights are of considerable importance some figures of standard practice, especially as affected by cycle, speed and number of cylinders are of value and these are shown in the following table as averages.

AMERICAN MOTOR BOAT ENGINE WEIGHTS PER HP.

Number of Cylinders	Two Cycle			Four Cycle		
	0-500 r. p. m.	500-800 r. p. m.	Over 800 r. p. m.	0-500 r. p. m.	500-800 r. p. m.	Over 800 r. p. m.
1	50	40	30	80	65	25
2	40	30	20	75	60	18
3	35	25	15	70	55	12
4	30	20	10	65	50	10
6			5	58	45	5
8				55		4

These are in striking contrast to the weights of some stationary engines, which, for example, have exceeded 400 pounds per h.p. with, and 300 lbs. without flywheels.

Of the motor boats shown at the annual exhibition this year the average two cycle engine was of 9 h.p., 4.41″ x 4.58″, at 647 r.p.m. and weighing 39 lbs. per h.p., while the average four cycle engine was of 49 h.p., 5.09″ x 6.36″, at 823 r.p.m. and weighing 35 lbs. per h.p. (Motor Boating). This shows the tendency to limit the two cycle engine to smaller capacities and lower speeds. Of the two cycle engines shown, 50% had one cylinder, 43% two, 6% three and 1% four, while of the four cycle engines 3% had one cylinder, 15% two, 8% three, 48% four, 21% six and 5% eight. Of the two cycle engines 38% were of the two port and 62% of the three port and least efficient but simplest arrangements; while of the four cycle engines 44% had poppet valves on opposite sides, 39% on one side, 11%

in the head and 6% mixed. Ignition systems on two cycle engines were 50% jump spark, 42% make and break and 8% mixed, while of four cycle engines 45% had dual, 24% single, 20% double, 5% make and break and 5% mixed make and break jump spark. This ignition equipment condition is quite different from the automobile where the jump spark with D.C. generator predominates and from the stationary field where make and break is almost universal.

Internal combustion or so-called gas tractors for road, and locomotives for rail haulage, developed first from the stationary engines of the farm type located on wagons to be drawn by horses for portability. These were subsequently geared to the wheels of those wagons to constitute a tractor without any engine change, whatever, though later modifications were introduced in the design of the engine to more particularly adapt it to traction purposes, and today about half of them are built along the automobile engine line, which has been adopted bodily and set on the frame. There is practically no weight limitation to the engine of a tractor or locomotive, which must be heavy to secure traction. The problem is thereby fundamentally different from that of the automobile and railroad motor car. While the total weight of locomotive or tractor may be reasonably high, there enters the limitation that the weight must be properly placed with reference to the traction wheels, usually only two. This bears directly upon the subject of redesign of the engine. The old stationary farm engine as originally installed carried a fairly heavy bed plate and flywheel and as mounted to get room for the gearing the crank shaft was set parallel to the axle and forward, the cylinder head pointing back. This threw the center of gravity too far forward. Two classes of modification were, therefore, developed, the first was to leave the shaft and gears where they were and reduce the weight of the engine, by using higher speeds and cutting down engine bed and flywheel, putting the weight so saved into the frame and wheels of the tractor or locomotive. The second was the adoption of the automobile engine with a different set of gears to permit the engine to be moved fore and aft where its weight would do the most good.

Out of this development, started by the manufacturers of

agricultural implements, there have been produced what might be described three different industries to which, of course, the automobile has also contributed. The first and largest of these is the manufacture of road or farm tractors including road rollers, which are now, so far as engines are concerned, of three classes; that retaining the original farm engine of one or two cylinders of moderate speed and heavy; that with reduced weight of higher speed and at least two cylinders with minimum frame and flywheels, and finally that which is distinctly of automobile type, high speed and four cylinder. These tractors are now built in sizes from about ten to nearly one hundred horsepower, and the tendency is to reduce size to reach the maximum number of small farmers. Tractors are all low speed machines, two to three miles per hour, so that much gearing down is essential, especially as tractor wheels are often as large as nine feet in diameter. The second new industry is that of the internal combustion locomotives which is a logical development of the last type of tractor as it is also a low, though higher speed machine for hauling, but now on rails. The standard engine at present is a four cylinder vertical engine of moderate speed, being more marine than automobile in class, geared to driving wheels to give locomotive speeds ranging from four to ten miles per hour, and weights from three to about twenty tons, the larger size having engine cylinders about 9″ x 16″. The third new industry of the group is that of self contained railroad car built now in a wide range of sizes, and car speeds up to and exceeding a mile a minute and using the four cylinder or eight cylinder "V" automobile type engine from 50 h.p. to 300 h.p. per car. The two leading styles differ radically in drive, one having direct gear drive with variable engine speed, and the other operating electric generators at constant speed with electric motors on the trucks, electrically controlled for speed and torque. In this class of service engine weights must be low, contrary to the tractor and locomotive requirements, and the electric drive 250 h.p. engine, probably the highest development, eight cylinder "V", weighs about 35 lbs. per h.p. exclusive of electrical equipment.

Stationary engines are all water cooled beyond a few small ones of about one horsepower. Up to approximately 400

h.p. they are all single acting, but both horizontal and vertical, single and multi-cylinder, though multi-cylinder engines are almost exclusively vertical, and horizontal engines almost exclusively single cylinder, though there is now a slight tendency toward multi-cylinder horizontal units. Except for a few single acting tandem engines, each cylinder has its own crank. Above 400 h.p. while there are a few multi-cylinder vertical engines; the number is small, most of these large engines being double acting and when double acting, single, tandem and tandem twin cylinders but with never more than two cranks and then usually of the overhung instead of the center crank type. Double acting engines of any one builder are made in only a few sizes of cylinder, commercial capacities being obtained by multiplication. Thus, a 500 h.p. double acting cylinder will make tandem 1000 h.p. and tandem twin 2000 h.p., or a 1200 h.p., the largest single cylinder make, 2500 h.p. tandem, and tandem twin 5000 h.p. sizes. All double acting engines have been kept horizontal because the great weight of the water cooled reciprocating parts, including piston and tail rods, crossheads and pistons, has been so serious a handicap that no designer has yet dared to build them of the vertical form though there is every reason to believe that vertical engines of this type will be built some day, following the vertical single acting, tandem engines that have recently appeared.

In point of numbers produced and used, the single cylinder horizontal engine is far in the lead. It is built in styles ranging from the cheap form, primarily designed for farm use, but equally adapted for small shop drives of hit-and-miss regulation and operating on gasoline, up to the highly refined and expensive modern development and is often doubled in two cylinders, but not more. Next in order of number comes the multi-cylinder vertical of two, three and four cylinders. Both the multi-cylinder vertical single acting engines and single or double cylinder horizontal cheap design, average about 200 lbs. per h.p. in larger sizes and the single or twin single acting horizontal ones of refined design about 300 lbs. per h.p. without flywheels, about the same as the double acting horizontal engines.

With very few exceptions, stationary engines are all four cycle though great numbers of successful two cycle engines

have been built, tried and retired, because of inefficiency, and of difficulty of control at light loads in all cases where mixture is admitted to the cylinder, that is, in all except the oil injection classes. This inefficiency of two cycle engines is due partly to escape of unburned fuel in the exhaust, arising from the necessarily non-homogeneous charge that is formed when a fresh charge directly displaces a burnt charge, diffusing at the surface of contact. This same non-homogeneity of charge is responsible for the uncertainties of operation at light loads when burnt gases so largely prevail in the cylinder. Low two cycle efficiency is, however, largely due to the fact that two cycle cylinders must necessarily run at a higher mean temperature than four cycle because of the double number of explosions per minute which requires reduction of compression. Finally, the negative work of the pre-compression charging pumps is a dead loss, which formerly ran as high as 15% of the motor cylinder work. It is now reduced in large engines to 7% or 8%.

Structural form of these stationary engines and their parts, while still in the evolutionary stage in some respects, has in general settled down to some well defined types that are worth review. Cylinder and frame arrangements have developed from the original horizontal type of overhung cylinder, bolted at the forward end to a symmetrical frame casting which carries the main bearings of a center crank, cylinder and jacket being cast in one piece and with a separate head bolted on. This is still retained but with modifications, all of which must be considered with reference to this as the starting point though some of these changes are quite material. The overhung or end connected cylinder with jacket cast in one piece is today the standard for both horizontal and vertical engines up to certain sizes, at which size a change is introduced, prompted by the two separate considerations. When the size becomes large enough, somewhat over 12″ bore, the difference in expansion of internal barrel and external jacket due to the differences in their mean temperature, is appreciable and unless the internal walls can expand independently of the outer, distortions that promote wear and impose injurious stresses will take place. In the case of the large horizontal cylinder, the excessive gravitational moment of the overhung cylinder connection requires bottom sup-

port under the head end, but this bottom support must be of the free sliding variety rather than a bolted down fixed joint.

Two typical constructions have been developed to provide for the expansion of the inner barrel. The first of these adapted to single acting engines involves the extension of the frame backward to the head of the cylinder, to which point of support both the cylinder and the head itself are bolted. The frame thus backwardly extending constitutes the water jacket wall and the cylinder proper becomes a liner held at the head end but free at the crank end. This system is practically a standard for all the better class of single acting engines. The jacket is truly a part of the engine frame, resisting not only lateral forces but taking up longitudinally the thrust between the cylinder head and the main bearing. The cylinder proper or liner resists bursting stresses but is relieved of longitudinal stresses as it can expand through a slip joint at the crank end. A second modification of the old one piece cylinder and jacket was originally developed in one of the better types of single cylinder horizontal engines but has been adapted to the large double acting engines for which it is now standard, though it is not yet used in vertical engines to which it seems as well adapted. This involves the transmission of the longitudinal forces or head thrust through the inner or true cylinder barrel, the jacket no longer acting as a frame, but merely as an enclosing envelope with an expansion joint between it and the cylinder. This is a lighter construction because the cylinder barrel if strong enough to resist bursting, is more than strong enough to resist horizontal stresses. It may, therefore, act as a frame member just as it does in steam engines and have for the jacket the simple function of holding low pressure water. This construction is well adapted to the double acting cylinder, a connecting yoke joining cylinders at their ends by the same type of joint as connects the forward cylinder to the shaft frame. These two alternatives avoid excessive thermal stresses but also make it possible to secure better cylinder castings, especially in the former case of liner construction, which is so far confined to single acting engines, both horizontal and vertical, and which is the heavier of the two, necessarily. Large double acting cylinders are often cast in two pieces and these are easily fitted with hard liners to

avoid reboring, held by a center ring between the two parts of the cylinder casting.

The old end to end connection between cylinder and frame that started with the original overhung horizontal one piece cylinder and jacket, without provision for its expansion and extension, remains the standard for all types of small and some fairly large engines, with one exception. This exception has been developed for small cheap horizontal engines, though used in a few large ones, and consists of a side connection of cylinder to frame by lugs or flanges, cast on the former, resting on two flat surfaces machined on the frame. It saves machine work at the expense of metal and is proper where weight is of no consequence and cast iron cheaper than labor.

Head constructions have passed through a somewhat similar series of changes to the present standards. Originally, heads were separate castings, bolted to the cylinder and with cored holes for communication of the cylinder water space with that of the head jacket. The difficulties of keeping this packed joint tight against outward hot gas flow and inward water leakage, either of which is fatal, together with the expense of machining in small sizes, has led to two modifications. For the small engines, especially the high speed automobile engine, the type construction adopted was the single jacket cored, casting for both head and cylinder, extended in some cases to include four cylinders in one. In some cases sheet metal jackets have been used around the barrel. They can hardly be reported as in general use though they should be where low weight is important. Recently, however, it is interesting to note that the one piece cylinder and head construction is becoming less standard because of a tendency to adopt the separate head, which has always remained the standard for stationary engines and which provides the necessary accessibility of the interior parts. The first bold departure in head construction was taken when the head jacket was made entirely independent of the cylinder jacket, leaving the packed bolted joint solely a dry gas joint, for which it can be properly packed, a step which was taken originally in the larger size of single acting vertical engines and is now one of the accepted standards.

The introduction of the double acting engine had led to a

further modification of head construction, which appears to be so fundamentally sound as to warrant general acceptance elsewhere. Starting with the conclusion that the valve ports must be located in the cylinder casting and not in the heads of these big horizontal engines, and that the width of the jacket space must be properly large to secure the long radius of curvature of the port walls to minimize expansion stresses developed by internal expansion, the cylinder bore has been carried clear through to the end, past the ports, and the head turned true externally to enter the bore instead of resting against a flat end face. In this case the head jacket is confined to that part of the head casting which enters the cylinder bore without any lapping over on the end face of the cylinder casting. This provides the most easily removable head and the most easily packed head joint, which may even be a ground one. It is a simple construction and one which might be used with profit on all other classes of engine.

Frames of horizontal engines are all heavy castings, not materially different, except for weight, from those of steam engines, but vertical internal combustion engine frames are almost universally of the box type, in striking contrast to steam engines which are either of open steel column or cast "A" type for light weight and accessibility. There is, however, a recent well marked trend toward adoption of these vertical steam engine frames in the interest of weight reduction and ease of inspection, especially in marine engines, and there is every reason to believe that the future vertical engines will be built with more cast "A" or steel column frames and fewer box frames than in the past, though piston leakage permits the escape of smoke and foul gases that box frames confine. Steam engine tendencies are also noted in an increased use of crossheads on some large single acting engines, which is interesting, as the old original Otto engine was so built.

Valves and valve gears of internal combustion engines have passed through a series of changes, beginning with the external Otto slide valve, resulting in the universal adoption of the poppet valve. The poppet valve of conical seat type is the only form so far proved to be capable of resisting successfully both the high temperature and the large stresses. It has not, how-

ever, proved quite satisfactory as to leakage, and when large, it does impose on its seat excessive localized crushing stresses that promote destruction and leakage. This dissatisfaction is responsible for the present search for something better that has so far resulted in extensive experimental trials of balanced sleeve, piston, internal slide, and various forms of cylindrical or tapered plug valve. This has resulted so far in demonstrating that any form of sliding surface valve can be kept cool enough if working against water jacketed casings, even when wholly within the combustion chamber, if it is not too thick, and if a good oil film is maintained to keep a thermal path of low resistance so as to keep down the thermal gradient. Great interest is concentrated on this problem as it may, if successfully worked out, have important influence on the design of large engines where so much of the cost is due to the difficulties of setting and driving of the now standard poppet valve.

Almost every conceivable arrangement of valve gear has not only been tried out but brought into commercial use and at first it seems impossible to draw any general conclusions as to typical practice, but a few well defined principles have been developed. Poppet valves in small and medium size engines, operating at not too great a speed, especially of the low priced class, are largely of the so-called automatic type, that is, opening and closing by the gas pressure without the assistance of cams. This type of valve construction involving as it does considerable inertia, is excluded from all large engines and from high speed small ones. It is also excluded from those engines where high efficiency is desired, because of its high suction resistances which introduce negative work and reduce cylinder volumetric efficiencies. It is, therefore, confined today to engines of the farm class and some low speed boat engines.

With this exception the common poppet valve is normally cam opened and spring closed, on all existing engines of every size and type, and the valve itself is of one piece solid construction except in the very largest sizes of exhaust valves, which until recently have all been hollow for water cooling though recently the extra complication and expense of this has led to trials of plain solid exhaust valves.

It is in the location of the valve, the mode of attachment

and driving gear that the great diversity of practice is found. Valves are set with stems both horizontal and vertical, even in one engine; both stems in the head, both in the cylinder or one in each; stems parallel to the axis of the cylinder or at right angles and pointing up or down, right or left. Sometimes the two stems are parallel side by side, sometimes parallel opposed, both in and out of line, but just as often they are otherwise placed. A horizontal stem poppet valve, especially when the stem bearing becomes worn, or the stem is not sufficiently stiff, will normally seat eccentrically and this will make it wear out of round and become leaky. Not only is it of very great importance for the valve to seat squarely for tightness, but also for keeping the seat and valve face true to properly distribute the high seat stresses, due to the large gas pressures, on the valve head. This seat stress, in large valves and engines of high maximum pressures, especially the Diesel class, may become so great as to actually crush the metal at the point of contact. It may be said, therefore, that the standard positioning of the valve is confined to vertical stems. Horizontal stems are to be condemned as utterly out of the question in large engines, and are permissible only as a make-shift for reducing cost in the smaller engines where the valve weight is small and tightness and life of small consequence compared with first cost.

Even with the conclusion that the standard positioning of poppet valves must be vertical, the situation while partly cleared up is not entirely so, for it is necessary in addition that the stem be sufficiently stiff, the stem bearing sufficiently lubricated and the seat sufficiently cold to resist the constantly present wearing influences of impact and hot gas erosion. In addition to these considerations, which are not difficult to meet, once recognized, there is the more general consideration of equal importance, that the valve location be such as to provide for the maximum simplicity of the cylinder and head castings and the maximum accessibility of the valve for inspection, regrinding and replacement. Proper stem stiffness requires an amply large diameter, larger than is normally employed. Long stem bearing life is insured by long lubricated bearings, preferably provided with replaceable bushings. This requires a stem stuffing box, the importance of which is very great though little

recognized. There is an almost complete absence of stuffing boxes on the stems of existing engines. The primary object of the stuffing box is, of course, to prevent the consequence of leakage. Even a slight leak past an exhaust valve stem will result in the blowing out of all lubricant on each exhaust period. Exhaust valve stem stuffing boxes are used on some of the better class of larger engines, but on no small or medium sized ones. Leakage past an inlet valve stem is just as serious on all engines that are throttle controlled and taking mixture during suction. This includes all engines except the farm type with its hit-and-miss governor, a few large engines governed by variation of proportions and the injection oil engines. During light load with throttle nearly closed the pressure at the inner end of the stem bearings may be as low as one-third of an atmosphere, and is always acting and causing leakage of air regardless of the valve position, whether open or closed. This will dilute the mixture, interfering with the air and gas proportioning apparatus, or the carburetor, but will also carry inward all lubricating oil and keep the stem dry. It seems clear that the present tendency not to use stuffing boxes on poppet valve stems must change to a standard adoption of them on all first class engines designed for long life.

Proper seat life is equally important and this seems to be quite generally recognized. Gas leaks erode both valve face and seat to a surprising degree at high temperature. This is met partly by original design and partly by frequent regrinding. This regrinding is facilitated by the mounting of valves and springs complete in removable cages, which can be replaced in a very short time if spares are kept on hand, allowing the regrinding to be done at leisure. This construction must be regarded today as the standard high class practice for the inlet valves on all sizes of engines and for the water cooled exhaust valves of large engines. It is not universal for exhaust valves that are uncooled. Inlet valve settings do not require special cooling provisions as the incoming charge will accomplish all the cooling that is necessary, though, of course, the corresponding charge heating decreases the volumetric efficiency and mean effective pressure. Exhaust valves, however, are heated on the combustion chamber face during each expansion, and on the

outer face and stem during each exhaust stroke. This is quite sufficient to produce a red heat in operation, at which temperature long life is very difficult with any metal and would, of course, be aggravated by uncooled cage settings. The expense of these separately jacketed exhaust cages has limited them to large engines, the smaller ones adopting instead the plan of seating the exhaust valve directly on the water cooled castings of head or cylinder, and carrying the water jacket around the valve pocket and stem bearing, extending it in some cases to the exhaust pipe connections to limit back conduction of heat.

Valve gears regardless of size or type of engines all have a cam as one element, but there is a most surprising difference of detail in the operating mechanisms, not pertinent, however, to the lines of standard practice. These cams on all small engines of the rotating class are made in one piece with, or in larger sizes keyed to, a half speed cam shaft. Valve motion is taken from them by rollers provided with side thrust mechanism, through a system of linkage rods leading to the valve stem. All large engines with one exception have abandoned the rotating cam because the large inertia of the reciprocating parts between cam and the valve stem, which inertia introduces large unnecessary valve gear forces. This heavy linkage inertia on opening the valve imposes excessive acceleration loads on the roller and cam, in addition to the spring load. This spring load itself must be very large to give a proper high speed of closure to the heavy linkage. To limit this excessive spring load and linkage accelerating force, together producing excessive cam and roller loads, practice in this respect has been standardized to the use of the oscillating or wiper type of cam as close as possible to the valve stem itself, all connecting linkage being positively driven in both directions by an eccentric. The better class of horizontal engines of all sizes, both single and double acting, locate the half speed shafts parallel to the axis of the cylinder carried on bracket bearings and extending the entire length from crank shaft to cylinder head. This provides ample room for not only the cams or eccentrics but also for governor, pump and igniter drives. The thoroughly good characteristics of this horizontal half speed cam or eccentric shaft are such as to make it unlikely that it will ever be changed for the large

double and tandem engine, though its high cost makes it likely that a horizontal single acting engine may ultimately adopt another form. One alternative construction originally developed for the small cheap engine is subject to a modification that makes it a serious competitor. This is a very short half speed shaft parallel and close to the crank shaft carried on the frame, with long push rods, to operate the valves directly or through rocker arms. On the larger engines these push rods, which act as long columns, would, if made stiff enough, become so heavy as to introduce excessive inertia, but this difficulty can easily be met, though it has not been as yet, by the substitution of tension rods for push rods, placing the roller on the opposite side of the cam shaft. There is ample justification for this simple and cheap valve gear, which lends itself not only to the horizontal engine, but equally well to the vertical and to the multiple as well as to the single crank, since a cam shaft parallel to the crank shaft can be extended indefinitely across any number of cylinders.

Design of the parts and groups of parts of engines and auxiliaries that have contributed so much to advance the internal combustion engine, and that require further development and perfection to extend their field of influence, might be profitably discussed at great length but space forbids more than a mention of a few. These include selection of materials, lubrication, regulation, mixers and proportioners, gas regulators, meters, starting, exhaust piping and silencing, ignition systems and apparatus, water cooling and purification; plant heat economizing appliances, air and water pumps and tanks, gas cleaning and tar extraction; oil heaters, pumps, injectors and spray nozzles; packings, pistons, piston rods, stuffing boxes,cross heads, governors, crankshafts and flywheels; together with the variable speed transmission, reversing and disengaging systems and apparatus that have been and still are such essential factors in the adaptation of internal combustion engines to vehicles and boats.

Throughout the whole active period of internal combustion engine development, during the early part of which accidents and failures were so frequent and discouraging, the one big compelling force that has kept up hope and that therefore has been, as it is today, the basic reason for keeping on with the

good work, is the scientifically sound basic principle or theory of efficient conversion of heat into power by internal combustion of gases properly controlled. While in the early days engines were built without any thought of the thermodynamic cycles they were to execute, without any primary idea of the limits and possible performance fixed by thermodynamic considerations, without any knowledge of, or interest in, the properties of explosive gaseous mixtures and the limitations or possibilities imposed by those properties on the treatment of such mixtures in cylinders—that time, characteristic of the birth of the art, has definitely passed. In the interim, which represents the youth of the art, there has been built up a body of basic data and principles, constantly growing, that permit of the determination with ever increasing accuracy not only of the limit of possible performance of engines but what is even more significant, of the analysis of the energy losses into their constituent parts and the evaluation of interferences still suffered by engines now in service. With the present state of knowledge on the properties of explosive mixtures and on the distillation, vaporization, gasification and combustion of fuels, the first fundamental step in the design of gas engines for specified performance is on a truly scientific basis. The determination and prediction of the behavior of the gases in the cylinder permit of a reasonably accurate evaluation of the gas pressures to be resisted and put the design of mechanism and structural elements on the same basis as exists in other classes of contemporary machines with one exception, and that is due to the unique thermal expansion and temperature stresses of those metal parts that are heated on the one side by the combustion and cooled on the other by water. These expansion stresses have not yet yielded to formulation, but progress in developing the laws of heat transmission and exchange is so rapid that the time seems near when even this will be possible and stress analysis of this class of machines become a matter of routine computation.

Thermodynamic analysis of gas cycles for transforming heat into work has become common, is even taught now in all engineering schools, and almost every conceivable possibility has been investigated both by computation and by proposals for mechanism to carry out each cycle. By these parallel proc-

esses of gas cycle analysis, and mechanism invention or design, the field of possibility is being pretty thoroughly canvassed and some of the best engineering thought of the day has been attracted to the problem of efficient generation of power from heat, alone and in cooperation with efficient heating and lighting. Mechanism designers and power engineers are, however, devoting even more attention to the mechanical perfection and adaptation of apparatus operating on the two adopted gas cycles, the Otto and the Diesel, both of which have high enough efficiency characteristics, both promised and realized, for some time to come.

DISCUSSION

Mr. Seshasayee. **Mr. R. Seshasayee,*** Assoc. A. I. E. E., opened the discussion by saying that the Blackstone engine is one of the crude-oil engines most largely used in India. He believed that America should supply an engine suitable for their needs, since at the present time they can not be easily secured from England, due to the difficulties in Europe. He considered this as a very appropriate time and place to bring up the subject of America supplying the needs of India.

He thought the hot-bulb type of engine was the best and should use air at from 400 to 450 lbs. per sq. in.

The fuel should be pumped into the atomizer with air and then both of these sprayed into the bulb, preferably at the end of the compression stroke as is done in the Blackstone engine. In their experience, after months of service, no carbon deposits are found as a result of this operation. Lead should be given to the air valve, so as to scavenge the cylinder thoroughly. With the valve set to open about ten degrees in advance of the dead-center position of the piston, when the oil is sprayed in with air at the end of the stroke, the combustion becomes more perfect. The exhaust valve should open at about 135 degrees of crank position and remain open until about ten degrees past dead center.

Their experience had shown that the use of the hit-and-miss type of governing, as applied to most engines of 30 hp. or less, had not been entirely satisfactory for constant speed. When used with electric generators, a variation of from 10 to 15 percent is formed in the voltage with this type of governing. All engines, small and large, should have gradual cut-off governors, which cut off the fuel supply, not by fixed steps as is done in some engines, but by unlimited fractional stroke of the fuel pump.

Mr. Peaslee. **Mr. W. D. Peaslee,†** referring to the statement concerning the reduction of engine weights and cost per hp. to meet the competition of steam

* Trichinopoly, South India.

† Portland, Ore.

plants, thought that it should be qualified by adding, "without lessening the high quality of materials and workmanship". A study of several notable failures in the United States had shown that the weight of material and cost per horsepower were brought down by the use of inferior material and poor workmanship. Such action is fatal to the end in view. It must be strongly impressed upon the builders that the grade of materials and workmanship must be kept as high as possible. The high pressures used in Diesel engines in particular require a high quality of machine. Mr. Peaslee.

Mr. E. H. Herbert‡ stated that his company now builds the Blackstone type of semi-Diesel engine which differs from the other semi-Diesels in that two sprays are used in injecting the fuel instead of only one as is usual. It will run light without overheating the bulb and self-maintains the bulb temperature while running. However, the bulb must be hot in order to start the engine. On a recent test at Coalinga, an engine ran for six months on Coalinga crude oil, including drips and other low quality of fuel, with satisfactory results. Mr. Herbert.

Prof. C. E. Lucke (by letter), in closing, said that ordinarily the small amount of discussion on so important a topic would be a subject of remark and regret, but in this case it is about what might be expected, because of the review type of presentation prescribed by the rules. It is confidently believed that in professional as well as business matters a periodic stock taking is essential to rational progress; and in this instance such a review as this must have good effect on an art and its resultant industries, where promise still exceeds attainment, due to ungrasped opportunities and past mistakes, even though results so far accomplished warrant a feeling of pride in all who have contributed. Prof. Lucke.

‡ Doak Gas Engine Co., Oakland, Calif.

Paper No. 123

THE DEVELOPMENT OF THE CONSTRUCTION OF TURBINES IN THE NETHERLANDS.

By

D. DRESDEN, w. i.
Mech. Engr. for Messrs. Gebroeders Stork & Co.
Hengelo, The Netherlands

Although the Netherlands are known to contain a lot of water, it is a fact that, up to a very recent date, no water-power has been used to any extent. This is to be attributed to the fact that there are no great differences in water-level. On the other hand, ordinary water-wheels have been in use for centuries, in many cases driving mills.

For the draining of our polders, various types of paddle wheels have been in use, being driven, even centuries ago, by windmills. A good number of such plants are still in existence and show that the art of building these windmills, constructed almost completely of timber, reached a great height.*

Driving the pumping plants for our polders was a good field for the introduction of the steam engine, which was first put to this use at the end of the 17th century.

The almost complete absence of coal, iron ore and mines in general in our country was not favourable, either to the manufacturing of steam engines, or to the development of industry in general. Still, soon after Fulton's trials, in fact about 1830, marine engines, as well as stationary engines, were built in our country.

The development of the means of communication, caused chiefly by the introduction of steam power, in its turn opened the opportunity for the development of various industries in

* Interesting particulars concerning the various types of pumping-engines that have been in use for draining our polders are to be found in "Polders en Droogmakeryen", Book II, Chapter II. (Edited by Gebrs. van Cleeff, the Hague.)

our country. The demands of this industry could only be covered by the application of steam engines.

With the introduction of electric light, a new field for the steam engine was opened. As long as the use of electricity had not attained the present proportions, most power stations could effectually use the piston engine. The steam turbine, with its small floor space and large units, did not become a necessity until the one-watt lamps and the use of three-phase current, with its cheap motors and extensive distribution systems, caused the demand for electricity to grow most rapidly.

By that time, only a few types of steam turbines (Parsons, Zoelly, Curtis) had crystallized out of the many proposed constructions, and it will be easily understood that the Netherland firm of Gebrs. Stork & Co., when taking up the manufacturing of steam turbines, resolved to procure a license for one of the tried systems. In view of the well known advantages of the action type of turbine (less blades, larger clearances, easier way of reaching a perfect balance, absence of dummies), they took out, in accordance with competent advice, a license for the Zoelly turbine.

We referred above to the almost complete absence of coal in the Netherlands. However, in the southern part of our country, where coal mines had been explored for centuries (in fact as early as the eleventh century), the Government took in hand the exploration in 1903; cheap fuel being available in quantities more than sufficient for the production of the electric energy wanted by the mine itself, the first cross-country power station was established here, equipped with the first turbines made in the Netherlands.

The manufacturing of turbines was taken up in 1906. In this first year, only three turbines, with a total output of 5100 hp., were ordered. The curves in Fig. 1 give the growth of the number and the power of the turbines ordered up to the present year, at the same time showing the growth in the average capacity. (The figures do not contain the turbines driving condensing plants, nor small turbines for driving boiler feed pumps, etc.)

Whereas, in 1904 the general opinion of dynamo builders was that above 1000 kilowatts capacity the number of revolu-

tions per minute should not exceed 1500, at present turbo-alternators of 8000 kilowatts are built with 3000 revolutions. The 3000 r.p.m. type is cheaper and more economical in steam consumption than the 1500 r.p.m. type, and of course takes less floor space.

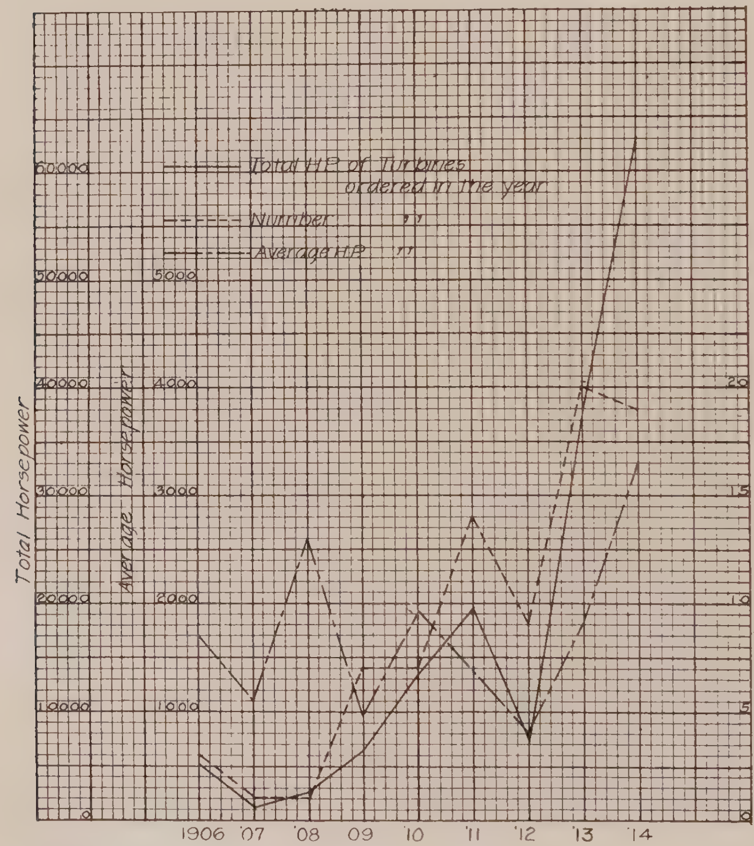

Fig. 1. Growth in Number, Power and Average Capacity of Turbines.

In the first turbines made in Holland, the designs of Escher Wyss & Co., in Zürich, the originators of the Zoelly turbine, were closely followed. Gradually, however, with growing experience, details have been altered, partly with a view to lowering the steam consumption, partly in order to make the

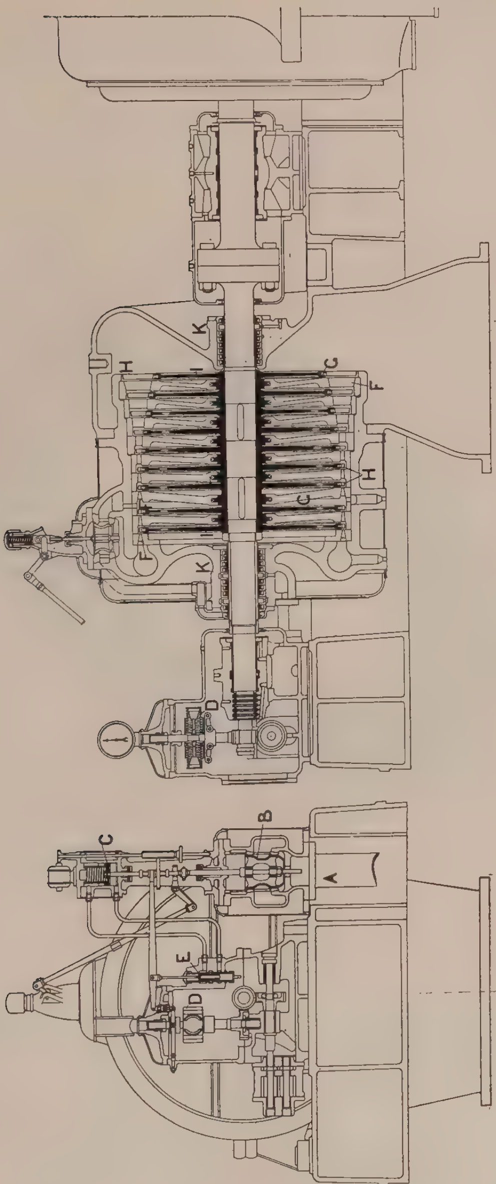

Fig. 2. Standard Zoelly Design of Turbine.

engine still more fool-proof, and partly to enhance the appearance of the turbine.

Although the standard Zoelly design is well known, it is shown in section in Fig. 2 in order to point out the most important items.

The steam, after entering at A, passes the throttle valve B, which is actuated by the piston C, under the influence of the

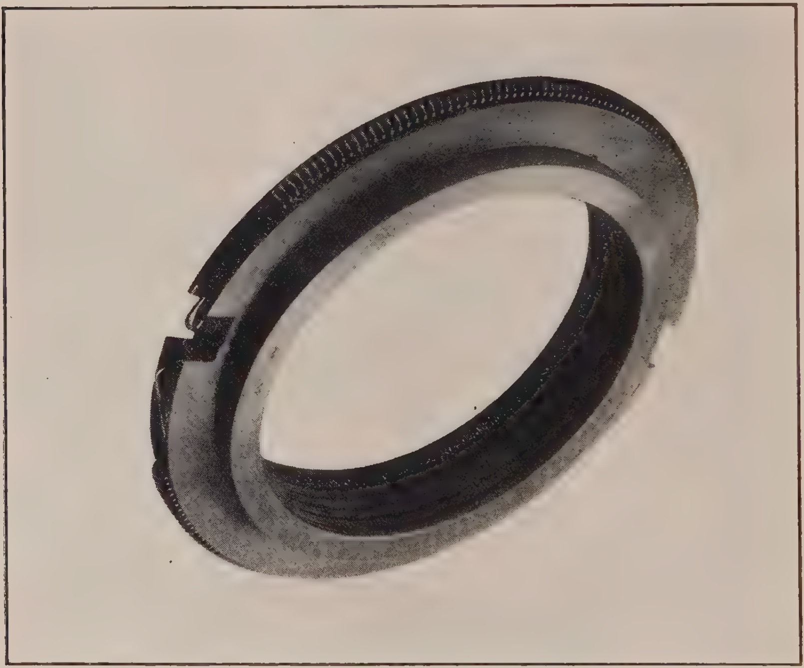

Fig. 3.

regulator D and the piston valve E. The steam is allowed to expand in the fixed blades F, cast in the discs G, and causes the moving blades H, fixed in the wheels I to rotate. The shaft passes through the discs G and the casing K, so that at these places means have to be provided to limit loss of steam and to prevent air leakage. An improvement in this respect was the introduction of movable rings, made of a special bronze, Fig. 3. These rings are made in halves, the two halves being pressed

together by springs, leaving only a small clearance and forming so-called labyrinths; the bottom spring is stronger than the top one, thereby compensating for the weight of the ring. The clearances are made in such manner that, all being in working condition, ring and hub do not touch each other; if, however, by some cause or other, a slight vibration should cause the two to come into touch, the rings are able to follow these motions and the material is able to bear the friction without gripping.

The same labyrinth principle is applied in the so-called "stuffing boxes". Here rings of a special alloy were used, which however needed a slight lubrication. This has been avoided by the use of carbon rings, consisting of three parts, which are accurately lapped together, with a clearance depending on the temperature. No absolute tightness being obtained in this way, the vacuum is sealed by steam; the steam leaking through the H.P. side is led into the L.P. part of the turbine. The rings are kept together by springs and kept from rotating with the shaft.

A very important place is taken by the bearings. At first, the turbo-generators were made with four bearings, two for the turbine and two for the generator, the shafts being coupled by a movable coupling. The firm of Stork designed a special coupling on the principle of the Oldham coupling which was successfully used, but the general tendency led to rigid coupling with four or three bearings. In some plants with four bearings, the movable coupling was replaced by a rigid coupling with good results, and at present almost all sizes are made with only three bearings, the more so because turbines with 3000 r.p.m. are prevailing.

These bearings are made throughout with a spherical part, on the Sellers principle, as will be seen in Fig. 2. The old form of bearing caps, with the overhanging parts, derived from the piston engine, was immediately dropped by Stork and a simple logical outline has been adopted.

With the exception of smaller turbines for driving condensing plants, etc., all bearings are lubricated by oil under pressure. (A few sets of turbine driven pumps, running at 2000 r.p.m. and of about 200 hp. each, have been built with ball bearings with excellent results. Ball bearings have also been

adopted for small generator sets at 3000 r.p.m. boiler feeding sets, etc.) At first, oil grooves were made in the bottom halves of the bearings, till later experiments taught the faultiness of this practice. As a fact, however, neither with oil grooves in the bottom halves nor without them have difficulties from insufficient lubrication arisen. The difficult problem of preventing any oil or oil vapour from leaving the bearing, or entering the generator, has been solved by providing ample spaces in the bearings for carrying off the return oil and by taking care not to have any part inside the bearing which might act as a ventilator, such as spray rings, couplings, etc.

The oil being effectively cooled before it enters the bearings, no complicated system of water cooling of these bearings is necessary.*

In most cases, besides the ordinary direct-driven oil pump, a steam pump is provided, preferably a turbine-driven centrifugal pump, which is used when starting the turbine. Sometimes a device is added which automatically starts this pump if the main pump should fail. The principle of centralizing all parts for the handling of the turbine is also applied to the lubrication, a valve box, containing all valves for this arrangement, being accommodated in the bed plate near the machinist's stand. All other handles (only very few are wanted, indeed) are within reach of the machinist.

The attendance of a modern turbine is very simple. All parts to be oiled are reached by the oil pressure system; among others, the centrifugal governor is completely enclosed and lubricated by the pump.

The use of turbines is not limited to the driving of generators. We have already mentioned the driving of pumps for condensing plants. For this purpose, two types have been developed by Stork. As long as direct current played an important part in the power stations and ample storage batteries were used, the condensing plants were mostly driven by direct-current motors. Driving by alternating-current motors had the drawback that, in case of a defect causing the engines to stop, no power was available for driving the condensation, so that

* Important facts on lubrication and the cooling of oil are given by G. Stoney in Engineering, Aug. 7, 1914.

the turbine had to be started with free exhaust. With growing three-phase sets, the storage batteries were no longer of sufficient power to drive the condensation plant, and this caused the introduction of turbine-driven pump sets. In some cases, the practice was to drive the pumps by a three-phase motor and to provide a turbine which, in case of emergency, could be coupled to the pumps. For this purpose, a simple form of turbine was developed by Stork, without a governor (an emergency governor is provided) and without insulation and coverings.

Driving the pumps by a turbine exhausting into the main turbine, although not quite so economical as electric driving, has come into use. For this purpose a somewhat more elaborate turbine is built, provided with a regulator, which is necessary here because the back pressure on the turbine depends upon the load of the main turbine.

In the case of these small turbines, as well as for the main turbines, the tendency is to increase the speed. A general speed for sets belonging to 3000-kilowatt units is 2000 r.p.m. For 6000-kilowatt sets, about 1500 r.p.m. are used (depending on the head for the circulation pump).

Another use for turbines is the driving of air compressors. Such sets have as yet not been used in the Netherlands, there being little or no demand for them in this country. At present, the first turbine for this use is in construction (1500 hp.; 4600 r.p.m.).

Driving high-pressure centrifugal pumps by steam turbines has been performed repeatedly, specially in sugar factories, where water-driven centrifugals are used. In these cases, turbines were used delivering their exhaust steam into the heating system. For furnishing exhaust steam, turbines have the great advantage that the steam is perfectly clean and free from oil. This has been one of the causes of the growing use of steam turbines in such cases.

Small turbine-driven pump sets are used as feed pumps. The automatic regulation is arranged so as to produce a constant difference in pressure between steam and water, independent of steam pressure or delivery. The difference itself may be changed according to circumstances (whether or not an economiser is used, etc.) by loading or unloading a spring.

Sets of turbines and direct-current generators for ship's use, running on ball bearings, have been built up to 200 kilowatts by Stork. These turbines have rather a high steam consumption, but require small space and little attention.

In general, we may summarize, that the development of the turbine shows two important points:

For the main sets, the tendency is to accumulate larger power in one set and to work with higher velocities, thus attaining less floor-space and better steam figures.

For driving accessory plants (and in plants using exhaust steam), the use of steam turbines is growing because of the clean steam they furnish, small dimensions, simplicity of attendance and reliability. In these cases, a relatively high steam-consumption does not count for much.

Marine turbines (for propulsion) have not yet been built in the Netherlands. In a few Netherland ships, turbines were used a few years ago, but were replaced by piston engines, as it was found that the piston engine was far more economical in these special cases. After that time, no new trials have been made. At present, however, one of our chief steamer lines has placed an order for a turbine driven steamer with Netherland firms and it is very probable that the turbines will be built by the "Schelde".

It will be of interest to give a few particulars of the history of the oldest engineering works in the Netherlands:

Fyenoord, at Rotterdam, developed from a ship owning company, established in 1823, which began business with one steamer and soon built a small shop for its own repairs. Its technical manager, Roentgen, soon gained an international reputation as a designer of steamers and marine engines and it is a remarkable fact that about 1830 he already understood and applied the principle of the compound engine. Original drawings of engines of that date are still in the archives. (Also see "Engineer" March 21st, 1890.) Ever since that time every description of marine engine has been built, as well as steamers, pumping plants and sugar mills.

At present the hands employed number about 2000.

The "**Werkspoor**", at Amsterdam, also originated from a ship owning firm which had established (in 1823) a steamer service between Amsterdam and Harlingen. In much the same way as with Fyenoord, a small repair shop was the origin of the engine works. With varying commercial success, these works developed on a spot where ships had already been built in 1608 by the East-Indian Company. Gradually more important machinery was made, chiefly marine engines and boilers, but also sugar machinery, etc. About 1891, locomotives and railway carriages were taken up, and this line has become most important. Last but not least, these works have gained a world wide reputation for building marine Diesel engines. At present about 2200 hands are employed by the firm, which is still closely related to a ship-building firm on the adjoining premises.

The "**Schelde**", at Flushing, was established in its present form in 1875, using the site of a former Royal Dock Yard, which was let to the founder. In 1876, the first steam-driven pilot boat for the government was laid down. These works built the first torpedo boats, iron-clads and cruisers constructed in the Netherlands, and also the first submarine (in 1904). All steamers for the "Rotterdamsche Lloyd" (one of the principal steamer lines to the Indies), since 1883 have been built by De Schelde. In 1876, two compound engines for Rhine steamers were built; in 1884, the first triple-engine in the Netherlands was constructed. In 1887, the first quadruple engine was delivered. Since 1902, De Schelde has held a license for Parsons steam turbines, but not until 1914 were any orders on turbine steamers booked. For the first sets of turbines (four sets were ordered by the "Rotterdamsche Lloyd"), parts will be obtained from abroad, but the necessary extensions for the construction of turbines are being built. In 1914, about 1900 hands were employed in these works.

The engineering works of **Gebroeders Stork & Co.**, at Hengelo developed from a small repair shop, in the vicinity of that place, established about 1858, at the time when factories began to use steam power. In 1865, the first steam-engine was built; in 1873, 100 steam-engines had been delivered.

As there is no navigable waterway in the neighbourhood, the development has taken place chiefly along the stationary

engine line, although since 1877, marine engines and boilers have also been built. Besides boilers, steam engines, pumps, transmission parts and hoisting machinery, the firm makes a specialty of sugar machinery, of which a good deal is in use in the Indies and in Cuba. Steam turbines have been built since 1907.

From 450 hands in 1894, the works developed to over 1500 hands in 1914. In this year, over 2000 steam engines and over 3000 boilers had been delivered.

DISCUSSION

Mr. Williams. **Mr. Fred L. Williams** opened the discussion by asking: "What are the present electrical efficiencies of motors and generators"?

Mr. Davis. **Mr. W. J. Davis, Jr.,*** Mem. Am. Soc. M. E., answered that the efficiency of direct-connected generator and turbine is as high as 98 to 98½ percent. In the U. S. Collier "Jupiter", the screw speed is 90 r.p.m. The efficiency of the induction motor connected to the screw is 94½ percent. The increase in the water rate of turbines when run at high speeds is great as compared with the electrical losses in generator and motor. The efficiency of the drive is largely dependent upon the propeller speeds. The use of alternating current is best and compels a lower turbine speed.

The mechanical gear reduction has proven satisfactory, even with as high a ratio as 40 to 1. The efficiency of the motor drive for faster screw is about 96 percent, as in the case of torpedo boats or torpedo-boat destroyers. This efficiency is due to the more efficient speed of the turbine and of the screw. It is not considered that the electric drive is applicable to merchant vessels, since the screw speeds are usually low in that type of vessel.

Mr. Dickie. **The Chairman, Mr. G. W. Dickie,**† Mem. Am. Soc. M. E., said that he believed the future for electric drive will be confined to ships with 5,000 horsepower or more per shaft. Where a vessel has to do much manoeuvering, an astern turbine is required and detracts much from the desirability.

The mechanical reduction gear of 18 to 1 gives good economy. Efficiency is maintained only with large installations and some low figures give a guarantee of eleven pounds of steam per shaft horsepower per hour.

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* Gen'l Electric Co., San Francisco, Calif.

† Consult. Engr., San Francisco, Calif.

Paper No. 124

THE 1915 STEAM TURBINE.

By

E. A. FORSBERG
Stockholm, Sweden

Sweden is one of the first countries where the manufacture of steam turbines was taken up. Already, at the beginning of the nineties, such a manufacture was carried on to a relatively large extent, and the turbines found an important market in the country as well as abroad. The foundation of this early industry was the type, invented and worked out by Dr. De Laval, with single disk wheel, rotating with high velocity, mounted on a flexible shaft, and provided with gear for reducing the speed to practicable limits. The first turbines were of relatively small size, but with the development of the manufacture and the gaining of experience, the size was increased more and more. The above-mentioned type was for many years the only one which was made in Sweden, and, as the manufacture necessarily is limited to smaller units, the consequence was that the great market could not be conquered by the Swedish turbine, which to a certain extent was a restraining influence on its further development.

Not until, through the work by Parsons, Rateau, and others, the relatively slowly running multiple turbines, practically possible for unlimited capacities, had been developed and had proven their practical suitability, was this phase of steam turbine technics duly considered in Sweden, and in 1906, the manufacture of such turbines was taken up in the country.

The only Swedish firm, which, at that time to any appreciable extent, carried on the manufacture of steam turbines, was Aktiebolaget de Lavals Ångturbin (The De Laval Steam Turbine Co.), the same firm that earliest appeared in this

sphere, and to a certain degree worked as a pioneer. Its work has, since that time, been divided according to two lines, viz, partly the original De Laval turbines of the one-stage action type, and partly the later produced multiple turbines, also working according to the action principle, and which may be characterized as a modified Rateau type. The first-mentioned ones are built for powers up to 500 hp., and the last-mentioned ones from the said power up to 15,000 hp. Each type has thus its field.

Lately a quite new type has been brought on the market by Aktiebolaget Ljungströms Ångturbin (The Ljungström Steam Turbine Co.). The manufacturers of this type are the Swedish licensees of the said company, Svenska Turbinaktiebolaget Ljungström (The Swedish Turbine Co. Ljungström). This turbine differs considerably from all earlier known turbine types, both Swedish and foreign ones. Classified as to the way in which the steam works, it is a pure reaction turbine, or Parsons type. As to the mechanical construction, it is, on the contrary, quite new.

The fundamental thought leading to the development of the Ljungström turbine has been the following: The cubic space occupied by a steam turbine is determined in two dimensions by the quantity of the outflowing steam, i. e., by the desired power. These two dimensions are those, which, either for the whole turbine or for each one of its elements, are at right angles to the direction of the steam flow. In the third dimension, on the contrary, i. e., the one corresponding to the direction of the steam flow, there is no theoretical minimum extension; but it is the question of strength, elasticity, and manufacture which is determinative. If we take, for instance, a Parsons turbine, it is evident that for a certain power and efficiency, given speed of the steam and fixed number of revolutions, the radial dimensions are once for all determined, so that nothing in this respect is to be gained. Regarding the length, this is, on the contrary, determined (the number of bucket series being considered given) only by the dimensions, which, from the point of view of manufacture and strength, must be given the buckets, and the clearances that, considering the possibly arising changes in the form, must be allowed.

Within all practically possible dimensions, the changes of the direction of the steam flow, which buckets and guide blades have to bring about, may just as well be effected if such parts have small or large extension in the direction in which the steam principally flows. Consequently, if it were possible, with the required area for the steam flow and the necessary strength and stability maintained, to construct buckets with less extension in the longitudinal direction of the turbine, a means would have been found to reduce the length of the turbine, and thus also its weight and volume. Besides the saving in weight and space which would, in this way, be realized, one could also reckon upon reduced losses of heat and, consequently, a better economy.

The solution of this purely mechanical problem was attempted by means of special bucket constructions and methods of manufacture which would permit their use. The method followed made it possible to realize the desired reduction of the dimensions, in such a degree, that the turbine could be built radially. This entails, among other things, the advantage that the speed of each bucket becomes the same along its whole length, whereby the losses in energy, due to friction and eddies, are the smallest possible. Of still greater importance is, however, the fact that the radial design permits the use of a double-sided rotation, i. e., there is no stationary guide blade system, but two rotating bucket systems, both taking up energy from the steam flow and serving as guide blades for each other. In this way, the relative speed between the elements from which the steam comes and to which it goes is increased, a circumstance allowing increased speed of the steam and, consequently, at the same time reducing the necessary dimensions and improving the economy. The elimination of the non-working, but friction-causing stationary guide blades, helps toward the same end.

In its present state, the Ljungström turbine consists of two reversely rotating disk wheels, each provided with a bucket system, consisting of buckets of small radial dimensions in which the steam expands according to the reaction principle. Usually each disk wheel drives a separate electric generator, and these two are coupled in parallel, thereby insuring even division of load.

Besides the two above-named works, some other firms build steam turbines which also are good machines, but as these types do not represent any original constructions, nor signify any pioneering work, it is not necessary to mention them in this connection.

The Swedish steam turbine industry is, consequently, so far as these two points are concerned, represented by the De Laval and Ljungström companies, and therefore a description of their respective designs with regard to the development during recent years, and the probable further perfection in the immediate future, will give a good view of the present situation of the Swedish turbine technics.

We begin with the De Laval Steam Turbine Co. as the oldest one.

The original single disk wheel type has lately been developed principally with regard to the attainable power. While it, for a long time, was limited to a maximum of 300 hp., a limit of 500 has now been attained. This has chiefly been brought about by improvements in the manufacture of gearings, which in some sort have been, and still are, the weak point of this type. Progress in the electric machine industry is also of importance, and the manufacture of perfectly running generators of required power and number of revolutions is now possible.

The turbine construction has not undergone any changes of importance since the adoption of the present form of the disk wheel, calculated to give a uniform distribution of the strain, the present construction for the fixing of the buckets and present type of flexible shaft, which made possible a device working with safety at the required high number of revolutions. It is also hardly to be expected that any important alterations will be made, as during the relatively long time it has been in the market, each detail has been thoroughly worked through. Neither is any appreciable increase of the maximum power to be expected, as the multiple turbines can now be built with very good results for powers down to 500 hp.

The development of the turbine with single disk wheel can therefore be considered to be practically terminated. However, this must not be taken to mean that this turbine type will not

be used in the future. On the contrary, for the powers for which it is built, it can be considered as a very suitable motor, which certainly will have a secured position in the market for a long time to come. Its simplicity, ease of operating, reliability and relative cheapness are factors that ensure it a given market, and, added to the above factors, its steam economy is very satisfactory. Some figures as to the results which can now be reached, in this respect, may be of interest. The steam consumption refers to dry saturated steam at a pressure of 10 kg. per cm.^{2} and at 84% vacuum.

Capacity, effective hp.	Steam Consumption, kg. per hp. an hour	Efficiency %
7	16.5	23
15	13.2	29
30	11.0	35
75	9.7	39
150	8.3	46
300	7.8	49
450	7.05	54

The principal interest is, however, attached to the multiple turbines. These are, as already mentioned, built according to the action principle, and most nearly compare with the Rateau construction. The development leading up to this present type might be of a certain interest to follow.

The first trials with multiple turbines had really for object to realize an idea that, theoretically, was well worthy of consideration, but in practice, did not meet all expectations entertained of the same.

As well known, it is possible, by means of so-called velocity-stages, to utilize the energy of the expanding steam by using a much smaller number of bucket series than is possible with pressure stages, whether they work according to the action or reaction principle. The difficulty with the velocity-stage is, however, that on account of the great speed at which the steam passes buckets and guide blades, considerable losses, owing to friction and eddies, arise. In order to prevent this, but at the same time maintain the advantage of a smaller number of series, it was proposed to give the buckets and guide blades such a shape that the speed of the steam within them was transposed

into pressure. The friction surfaces should thereby be considerably reduced, so far as that part is concerned which must be passed at great speed; hence, that the reversing of the direction of the steam flow could be done at low speed, which should reduce the formation of eddies and other disturbing conditions. It proved, however, that the transformation between speed and pressure, and inversely, did not take place as advantageously, in the trials made, as could have been expected, and, therefore, the final result was of little satisfaction. This construction was then given up, and the Rateau type more and more approached. The results thereby attained are very favourable.

The figures of steam consumption, which have been reached with normal turbines, are, it is true, fully satisfactory, but on the other hand they naturally are not record results, as the action principle, with regard to the attaining of the highest possible efficiency, of course, is somewhat inferior to the reaction principle. Efforts have been made to render the turbines, as much as possible, suitable for use in connection with arrangements for heating. This is a sphere to which, strangely enough, due attention has been paid only lately.

Most industrial plants need, of course, not only driving power, but also heat. This latter is required partly for heating premises, and partly for various other requirements, as for boiling, evaporation, etc. Only too often, it is found, even in modern plants, that the power- and heating-centrals are wholly or partially independent of each other, so that the power steam is immediately condensed, and live steam used for heating. This is, however, generally very uneconomical. The right way is to produce all the required steam at high pressure and temperature, and to let it work in a suitable prime mover, from which, at an intermediate stage, it is taken out at those pressures which are required for the different heating purposes. In case the direct requirement of heat is very great, it may certainly happen that the power-steam will not be sufficient, and then a special heating arrangement is justified; but this much is always certain, that direct steam should never be used before all power-steam has been consumed. If the consumption of power, as well as of heat, is very variable, it evidently will be a rather complicated problem, how the whole is to be arranged, so that the

total economy will be the best possible. If the requirement of heat is always so great that all the exhaust steam from the power machinery can be used for heating, and steam for this purpose of only a certain pressure is required, a steam-motor, working with counter-pressure, is the most suitable; but if, on account of the variations in the rate of demand, an excess of power-steam sometimes exists and sometimes not, it is rather difficult to find the best combination.

In order to meet the requirements, arising from combined power and heat demands, the De Laval Steam Turbine Co. has specialized in furnishing so-called counter-pressure and tapping turbines. The first-mentioned ones are, as the name indicates, constructed for work under appreciable counter-pressure, and, consequently, find employment, when it is desired to utilize, under all circumstances, all exhaust steam for heating. The last mentioned ones are intended for those plants, where, at least at intervals, there is an excess of power-steam. For the best utilization of the whole quantity of steam, it is, in this case, necessary that the steam be delivered to the turbine at the highest possible pressure and temperature, and, after it has expanded to the required lower pressure or pressures, and performed work during such expansion, is tapped, and the remaining steam completes its expansion and is condensed. Careful calculations are in each case necessary for determining the best dimensions of the different parts of the turbine, and this in some measure prevents a standardizing of the manufacture, and also involves the fact that such a tapping turbine cannot simply be compared with another turbine of corresponding power and working under the same pressure and temperature.

As example of the results obtained, the following figures are given:

Counter-Pressure Turbines.

1. Steam quantity, 8,500 kg. per hour
   Steam pressure, 10 kg. per cm^2.
   Steam temperature, 250° C.
   Counter-pressure, 1.5 kg. above atmospheric
   Obtained thermo-dynamic efficiency, 0.745
   Obtained power, 685 actual hp.

2. Steam quantity, 13,700 kg. per hour
   Steam pressure, 12.5 kg. per cm^2.
   Steam temperature, 280° C.
   Counter-pressure, 2.5 kg. above atmospheric
   Obtained thermo-dynamic efficiency, 0.690
   Obtained power, 900 actual hp.
3. Steam quantity, 8,100 kg. per hour
   Steam pressure, 9.5 kg. per cm^2.
   Steam temperature, 240° C.
   Counter-pressure, 3.5 kg. above atmospheric
   Obtained thermo-dynamic efficiency, 0.743
   Obtained power, 470 actual hp.

Tapping Turbines.

1. Steam pressure, 11.5 kg. per cm^2.
   Steam temperature, 300° C.
   Tapping pressure, 1 kg. per cm^2.
   Condensing
   Total steam quantity, 18,700 kg. per hour
   Amount tapped, 13,000 kg. per hour
   Condensed steam, amount 5,700 kg. per hour
   Thermo-dynamic efficiency of the high-pressure part, 0.70
   Thermo-dynamic efficiency of the low-pressure part, 0.70
   Obtained power, 2,300 actual hp.
2. Steam pressure, 10.5 kg. per cm^2.
   Steam temperature, 280° C.
   Tapping pressure, No. 1: 5.2 kg. per cm^2.
   Tapping pressure, No. 2: 1.2 kg. per cm^2.
   Condensing
   Total steam, amount 17,500 kg. per hour
   Amount tapped at pressure No. 1: 6,500 kg. per hour
   Amount tapped at pressure No. 2: 8,500 kg. per hour
   Condensed steam, amount 2,500 kg. per hour
   Thermo-dynamic efficiency of the high-pressure part, 0.705
   Thermo-dynamic efficiency of the mid-pressure part, 0.665
   Thermo-dynamic efficiency of the low-pressure part, 0.650
   Obtained power, 2,250 actual hp.

As to the turbines, built by the Ljungström Steam Turbine Co., with which we are now going to deal, the circumstances are quite different. As already introductorily pointed out, the Ljungström turbine is, in a quite specially high degree, adapted to give the best possible steam economy. The use of the reaction principle, the absence of the immovable bucket system, the radial device, the small dimensions—these are all circum-

stances contributing to a very good steam economy. However, in order to practically realize the possibilities the system offers, it has been necessary to overcome a great many difficulties.

This concerns in the first place the manufacture of the buckets. These must, in spite of their small dimensions, withstand a very considerable centrifugal force, which, especially towards the periphery, where the length is greatest and the centrifugal force reaches its highest amount, causes great stresses in the material, which, in reality, it would be impossible, even for the best material, to sustain, if special constructions were not adopted. The method used for the solving of this problem is that the buckets, at different places in their longitudinal extension, are provided with strengthening rings, so that the unsupported length is reduced to reasonable limits. Great purely constructive difficulties arise, however, in the fixing of the buckets in the rings and the bearing disks, and it is only with the help of welding by the oxyacetylene method, and various other artifices, that a satisfactory solution has been reached.

Another problem that it was necessary to solve is the equalization of the heat strains. Each bucket gets, it is true, on account of its small radial extension, practically the same temperature all over its extension, but the disks, carrying the bucket systems, and also other parts of great radial dimensions, are exposed to very variable temperatures at different points. The means by which this considerable difficulty has been overcome, cannot in this connection more closely be dealt with, but suffice it to say that such a perfect equalization has been reached that hardly any other turbine can work with such a high degree superheat as the Ljungström type.

A further difficulty is caused by the great axial pressure to which the bucket-bearing disks are exposed. This pressure is so considerable that, at the speeds of rotation used, it is practically impossible to take it up by thrust-bearings. The method has therefore been adopted of balancing the axial forces by means of steam pressure. This balancing is automatic, so that an elementary movement of the bearing disks in one direction or the other immediately causes a change in the steam pressure, counteracting the said movement. This automatic

regulating is ingeniously combined with the means for preventing leakage of the high-pressure steam, and has given the best conceivable results.

A weak point is, of course, that the electric generators must be made divided into two equal parts, which increases the cost and reduces the efficiency, but the experience has proved that these inconveniences are fully compensated by the superior economy obtained in other respects by means of this system.

It is, in fact, astonishing what small dimensions and how good an efficiency can be reached. The turbine disks with their bucket system are quite small machine-parts, hardly requiring any space as compared with the other apparatus. It can be said that the turbine is a small detail, arranged in the conduit from the boiler to the condenser.

A rather great number of turbines have, considering the short time they have been in the market, been built according to this system, and they have in all places given the best results. We give below the figures obtained with:

I. A 1000-kw. Turbine Built in Sweden.

Load kw.	Steam pressure kg. per cm. abs.	Steam temperature °C.	Vacuum kg. per cm. abs.	Thermo-dynamic efficiency %	Efficiency for turbo-generator %	Steam consumption kg. per kw.-hour
1000.5	10.79	313.4	0.0325	74.4	70.7	5.34
756.4	8.44	308.7	0.0281	73.7	69.4	5.55
504.7	5.82	304.8	0.0204	74.2	68.2	5.74
1000.4	10.47	354	0.0326	74.55	70.8	5.12
995.5	10.46	344.4	0.0326	74.7	71.0	5.16
1384.3	11.03	322	0.0703	75.8	72.0	5.61

5.5 kg. pr. KWH
12.5 / 165 " "
7.4 " " " H.P.

II. A 1000-kw. Turbine Built by the English licensees.

1013	12.6	210	0.0719	74.8	69.6	6.56
739	9.53	192.8	0.0565	73.9	68.7	6.95
487	7.02	183.9	0.0482	73.3	65.6	7.43
250	4.21	163.9	0.0432	72.4	58.65	9.09

For larger turbines, the results would of course be still more favourable. So are, for instance, the following calculated figures:

I. For a 2000-kw. Turbine.

Steam pressure kg. per cm.	Steam temperature °C.	Vacuum kg. per cm. abs.	Thermo-dynamic efficiency %	Efficiency for turbo-generator %	Steam consumption kg. per kw.-hour
15	350	0.05	80.74	75.9	4.84

II. For a 5000-kw. Turbine.

15	350	0.05	83.95	79.7	4.60

The above-mentioned obtained figures represent, no doubt, a world-record regarding the steam consumption for units of this size, and may hardly be surpassed by any turbines of no matter what size. Turbines are at present being built for a power of 10,000 hp., and they will doubtless give entirely epoch-making results.

A circumstance worthy of all consideration is the already earlier-mentioned fact that the turbines, on account of the favourable equalization of the temperature strains, can work with a very high degree of superheat. Besides, as there are no difficulties to prevent utilization of a very high steam pressure, the possibilities of a further improvement of the steam economy seem rather great. As a matter of fact, no other turbine construction seems to be so well adapted, as the Ljungström type, to realize the possibilities of increased thermic efficiency, which the development of the steam boiler technics will probably offer in the immediate future.

From the first appearance in the market of the Ljungström turbine, the fear has been expressed that the mechanical construction would be so complicated, and the difficulties in connection with the manufacture so considerable, that in practice the inconveniences should preponderate over the advantages. It must also be admitted that these fears *á priori* would seem

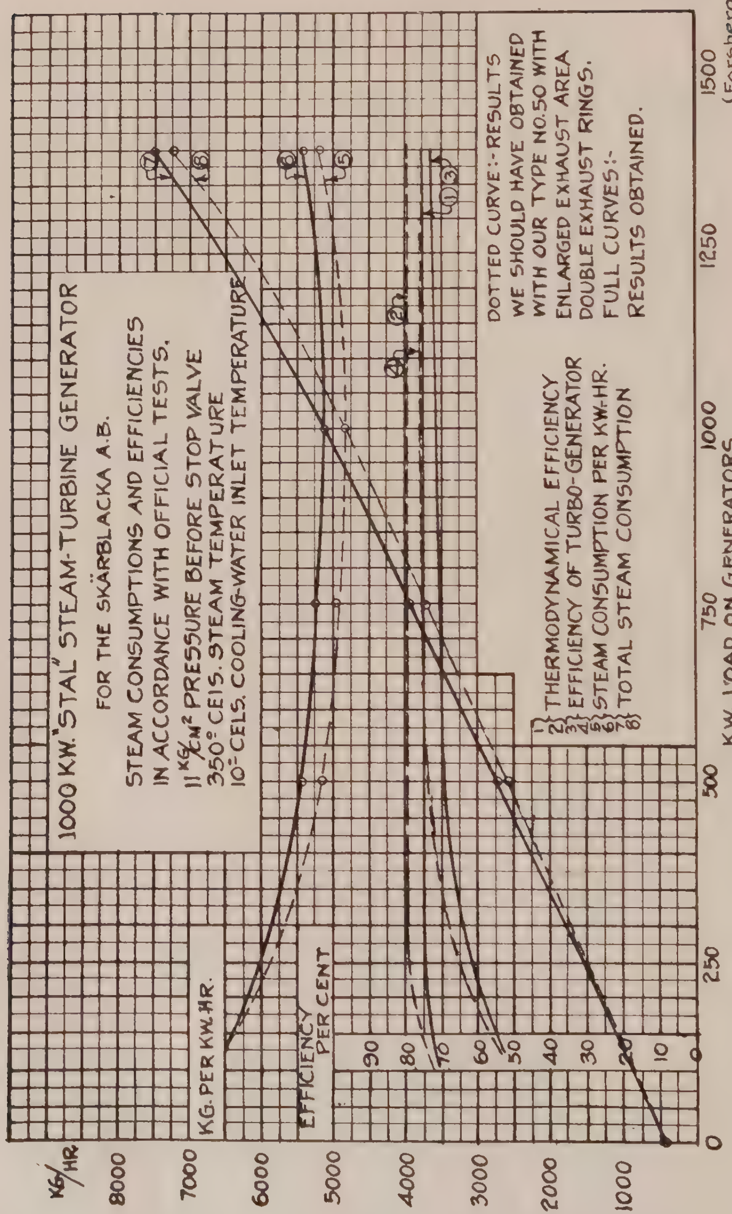

1000 KW. "STAL" STEAM-TURBINE GENERATOR
FOR THE SKÄRBLACKA A.B.
STEAM CONSUMPTIONS AND EFFICIENCIES
IN ACCORDANCE WITH OFFICIAL TESTS.
11 KG/CM² PRESSURE BEFORE STOP VALVE
350° CELS. STEAM TEMPERATURE
10° CELS. COOLING-WATER INLET TEMPERATURE
DOTTED CURVE:- RESULTS
WE SHOULD HAVE OBTAINED
WITH OUR TYPE NO. 50 WITH
ENLARGED EXHAUST AREA
DOUBLE EXHAUST RINGS.
FULL CURVES:-
RESULTS OBTAINED.
1/2 THERMODYNAMICAL EFFICIENCY
3/4 EFFICIENCY OF TURBO-GENERATOR
5/6 STEAM CONSUMPTION PER KW.HR.
7/8 TOTAL STEAM CONSUMPTION
KG/HR
8000
7000
6000
5000
4000
3000
2000
1000
KG. PER KW. HR.
EFFICIENCY PER CENT
90
80
70
60
50
40
30
20
10
0
250
500
750
1000
1250
1500
KW. LOAD ON GENERATORS
(Forsberg)

Fig. 1.

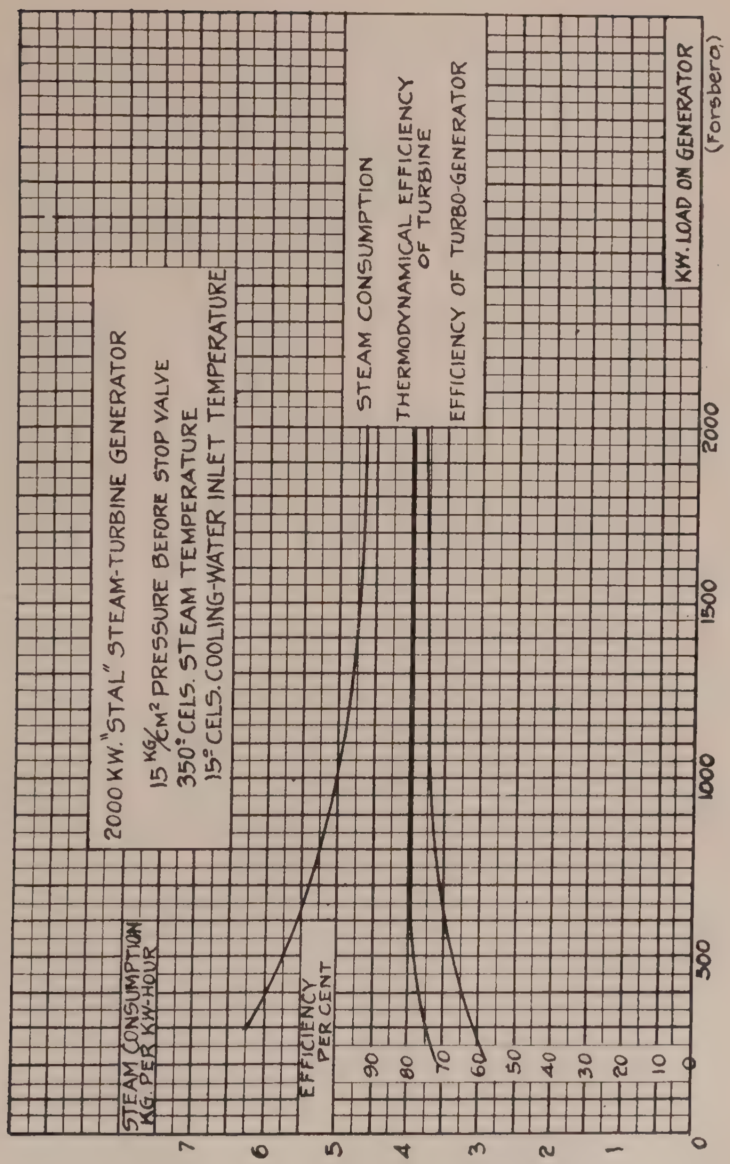

2000 KW. "STAL" STEAM-TURBINE GENERATOR
15 KG/CM² PRESSURE BEFORE STOP VALVE
350° CELS. STEAM TEMPERATURE
15° CELS. COOLING-WATER INLET TEMPERATURE
STEAM CONSUMPTION
THERMODYNAMICAL EFFICIENCY OF TURBINE
EFFICIENCY OF TURBO-GENERATOR
STEAM CONSUMPTION KG. PER KW-HOUR
EFFICIENCY PER CENT
KW. LOAD ON GENERATOR
(Forsberg)
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80
90
500
1000
1500
2000

Fig. 2.

well founded. Experience has, however, proved that these doubts, are not being justified, but it has, on the contrary, turned out that the manufacture can easily be carried out, and fully reliable machines be made. These turbines are now being built not only in Sweden, but the manufacture has also been taken up abroad and always with the best results.

A point that, strictly speaking, does not come within the range of this article, but owing to the peculiar circumstances should, we believe, be lightly touched upon, is the employment of the Ljungström turbine for vessel propulsion.

It is true that it still is only in the first stages of the trials, but the results obtained are such that they must be considered very promising. The only system that, for this purpose, has any prospect of coming into use, is the electrical, either directly, or combined with gearing. By using the electric transmission from the turbine, there is a possibility of getting the same work with a very high number of revolutions, which increases the efficiency and reduces the weight. Whether the electric motor shall act directly upon the propeller shaft or through a gearing, depends on the circumstances.

The present state of the development in question will no doubt be best explained by a short description of the only machine of this kind which has been built up to the present.

A large Swedish shipping company decided to build two vessels, which should be equal in all respects, excepting the machinery. This should, in one of the ships, be an ordinary triple-expansion steam engine, and in the other one a turbine aggregate of the Ljungström type. For the installation of the turbine machinery, it must be guaranteed that the turbine driven vessel should show a 30 per cent smaller coal consumption, as compared with the other ship. If this guarantee could not be kept, the turbine machinery should be removed and, at the expense of the manufacturers, be replaced by an ordinary steam-engine, of the same kind as for the other steamer.

The dimensions of the vessels were the following:

Length between p. p.	68.57 m.
Greatest beam	10.97 "
Moulded depth	4.72 "
Draught	4.50 "
Displacement	2225.00 tons

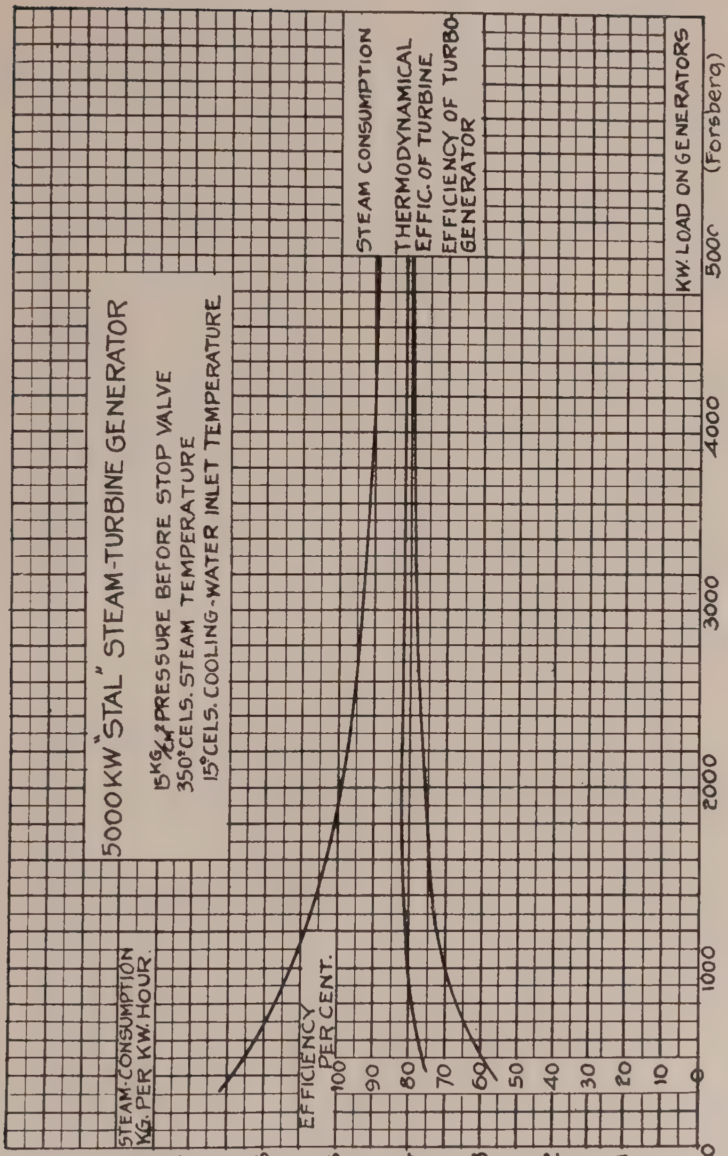

5000 KW "STAL" STEAM-TURBINE GENERATOR
15 KG/CM² PRESSURE BEFORE STOP VALVE
350° CELS. STEAM TEMPERATURE
15° CELS. COOLING-WATER INLET TEMPERATURE
STEAM CONSUMPTION
THERMODYNAMICAL EFFIC. OF TURBINE
EFFICIENCY OF TURBO GENERATOR
STEAM-CONSUMPTION KG. PER KW. HOUR.
EFFICIENCY PER CENT.
KW. LOAD ON GENERATORS
(Forsberg)
0
1000
2000
3000
4000
5000
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7

Fig. 3.

The calculated machine-power, for reaching a speed of 11 knots, amounted to 900 hp. at the propeller shaft.

The turbine-machinery was arranged in the following way:

Two equal units each of 400 kw. were erected. Each unit consisted of one turbo-generator with double-rotation, so that the generators were of 200 kw. each. The speed amounted to not less than 7200 revolutions per minute, and three-phase current of 500 volts and 120 periods was produced. This current was led to two motors, having a speed of about 900 revolutions, which by means of a gearing having a ratio of 1 to 10 drove the propeller shaft. The turbines were provided with governors in the ordinary way, and the speed regulation was obtained by means of variable resistance in the rotor winding of the motors. For merchant ships, which mostly go with full power, this arrangement was, owing to its simplicity, considered the most suitable.

It is evident that, apart from the possibly attainable reduction in coal-consumption, the turbine machinery offered the advantage of a greater security against break-down, as there always was some reserve, and it also gave absolute safety against racing in high seas.

At the comparative trials, with the two vessels under equal conditions, it turned out that the coal consumption for the turbine ship was only 58 per cent of that of the sister-boat, and that the guarantee was thus considerably surpassed. For the sake of justice, it must here be remarked that the turbine vessel worked with super-heating, which was not the case with the other one, but at any rate, there remains a very considerable advantage for the first-mentioned ship.

As to the weight of the machinery, this was 20 tons lower for the turbine vessel.

This first trial has thus proved very satisfactory, and it might not be too daring to say that there are great possibilities in this direction for the future.

For a more complete description of the Ljungström turbine, we refer to "Engineering" of April 12th and 19th, 1912.

Regarding the probable development in the near future, it is, of course, difficult to try to prophesy things, but without running the risk of making too great a mistake, it might be

possible to predict that the De Laval Company will more and more develop and standardize their counter-pressure and tapping turbines, and in this way, contribute to the solution of the very important question, especially for a country deficient in coal, regarding the best possible total economy in using the energy, bound in the fuel. The Ljungström Company, again, will very likely, in the first place, be occupied with further perfecting their turbines in the direction of a still greater improvement of the steam economy, and especially for the use of high-pressure and highly superheated steam.

Summary.

An account of the earlier development of the steam turbine technics in Sweden is given, and it is pointed out that Sweden is one of the pioneer countries in this line. The present Swedish turbine industry is principally represented by two firms, viz.: The De Laval Steam Turbine Co., and the Swedish Turbine Co., Ljungström, each one of which, within its department, has reached very good results. The former has specialized itself upon counter-pressure and tapping turbines, while the latter at present holds the world-record for steam economy, and also has made very satisfactory trials with turbo-electric vessel propulsion.

Paper No. 125

THE DIESEL ENGINE IN AMERICA.

By

MAX ROTTER, Mem. Am. Soc. M. E.
Ch. Engr. Busch-Sulzer Bros.-Diesel Eng. Co.
St. Louis, Mo., U. S. A.

It was the purpose of this paper to treat the general subject of the present status of the Diesel Engine; but, due to obvious and regrettable circumstances, the writer found himself so handicapped in obtaining anything like representative original information from abroad, except from the associates of the company by whom he is employed, that he has been constrained to practically limit the paper to the development of the Diesel engine in this country, and to address it primarily to American engineers. And, because the subject is less familiar to these engineers, there has been included in this paper certain historical and fundamental information, which is well known to and understood by those who have made a closer study of it.

Considering the large and ever-increasing production of mineral oil, in the United States, the residual products of much of which oil are suitable almost exclusively for fuel and are comparatively low-priced, the Diesel engine is peculiarly adapted to this country's requirements; and it is chiefly due to the meager consideration which was, until recent years, paid to economy in power generation, that this engine did not command the general interest or wide-spread usefulness that it merits. To this apathy was added active obstruction on the part of manufacturers of other types of prime movers, who were prevented, by the basic Diesel patents, from embarking upon the manufacture of this type of engine, and many of whom promptly engaged in this business, after the recent expiration of these basic patents.

The Diesel engine is the invention of the late Dr. Rudolf Diesel, of Munich, Germany; and it is a tribute that is due to his rare genius and almost unparalleled thoroughness, in the most painstaking, and often discouraging, theoretical and practical research, that a truer understanding of his aims be made more generally public on this occasion. These aims, and their pursuit, are clearly and fully disclosed in his "Theory and Construction of a Rational Heat Engine", published in 1893; and his "Development of the Diesel Engine", issued twenty years later, shortly before his regrettable death.

"Ignition by compression", so generally and superficially accepted as the fundamental principle underlying Dr. Diesel's invention, was, as a matter of fact, merely a natural corollary, and was not even claimed by him as his original conception; although typical of the engines that bear his name, and successfully employed in them alone. Dr. Diesel's great aim was a closer realization of the theoretical efficiency of the Carnot cycle than attainable by steam engines, or internal combustion engines of the ordinary types. And, although his aspirations were crowned with only a partial success, it is scarcely to be doubted that they created a heat engine which has the highest efficiency that will ever be attained with fuel.

In 1893, after many years of study and research, Dr. Diesel summed up his purpose, as follows:

"(1) The heating of pure air, in the working cylinder of the engine, by its mechanical compression by means of the piston, to a temperature far in excess of the igniting temperature of the fuel;

(2) The gradual introduction of finely atomized fuel, into this hot compressed air, and its combustion and simultaneous performance of work upon the out-moving piston;

(3) And (because a fuel can burn only after it has been gasified) the gasification of a non-gaseous fuel, gradually, in the working cylinder itself, in small quantities at a time for each stroke of the piston; the heat for gasification and ignition being obtained from the heat of compression".

Carnot's law, as applying to heat engines, is well understood:—the higher the initial temperature and the lower the terminal temperature, or the higher the initial compression pressure and the lower the terminal pressure, the higher will be the theoretical thermal efficiency of the engine. But the actually attainable efficiency is limited by the characteristics of the available materials; and modified by the mechanical losses, affected by the weight and dimensions of the moving elements of the engine. Dr. Diesel demonstrated that, although the theoretical thermal efficiency increased slightly beyond this point, the highest mechanical efficiency was attained with a compression pressure of 30 atmospheres, and a compression temperature of 500° C.; and, balancing these advantages against one another, that the highest actual efficiency, and the greatest useful power development per unit of cylinder volume, would be obtained by compressing the air to a pressure of between 30 and 40 atmospheres, and a temperature between 500 and 600° C.; and introducing the fuel in such manner as to obtain combustion at constant pressure, with a maximum combustion temperature between 1600 and 1800° C. On either side of these limits, the actual efficiency of the engine diminished. These deductions do not appear to have been proven incorrect, after twenty years of practical and diversified experience. It is self-evident that the stated compression temperature is "far in excess of that required" solely for the ignition of any carbonaceous substance which would ordinarily be used as fuel; also that, to avoid ignition during the progress of the compression, the fuel must not enter the cylinder until after the full compression has been attained.

In 1894 the first successful experimental engine, operating upon the above-described principles, was completed by Dr. Diesel. In 1897 Mr. Adolphus Busch, of St. Louis, purchased outright the sole rights to all Dr. Diesel's existing and future United States patents, and introduced the Diesel Engine into this country, under the sponsorship of the late Col. E. D. Meier.

The first Diesel engine built in the United States, was completed in 1898. Since then these engines have been installed in municipal and commercial central power stations, in the most diversified industrial plants, and as stand-bys for water powers;

in capacities up to 1000 brake horse-power. In Europe, stationary Diesel engines have been installed in units up to 4000 brake horse-power; but the relatively lower prices of fuel in the United States tend to retard a similar development here.

Following in the wake of the Diesel, or high compression constant pressure oil engine, has come the so-called Semi-Diesel, or low compression oil engine. The latter occupies a position between the Diesel engine and the older type of "hot-bulb" engine. The distinguishing characteristics of the two types may be briefly stated, as follows:

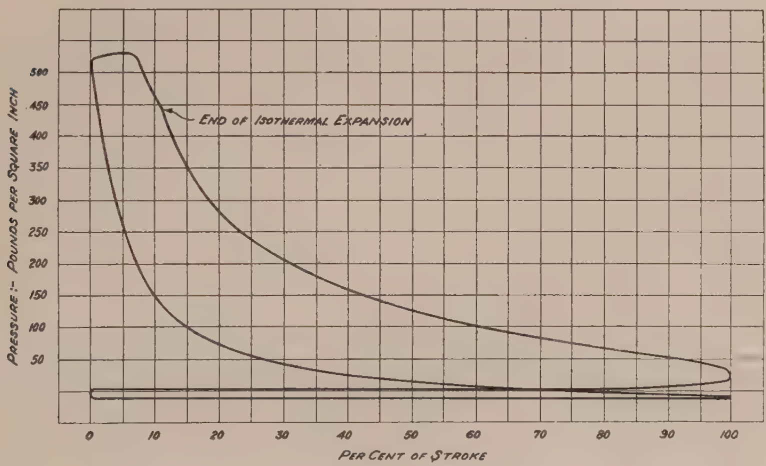


Fig. 1.

In the Diesel engine, the entire cylinder volume of pure air is compressed to the maximum pressure of about 35 atmospheres, and the corresponding temperature of about 500° C.; the fuel is introduced at or about the completion of this compression, and is gasified and ignited by the heat of compression; the combustion taking place without any material increase in pressure, but with a considerable increase in temperature, during 8 to 12 per cent of the piston stroke, and continuing during a subsequent period of isothermal expansion.

In the Semi-Diesel engine, the entire cylinder volume of pure air is compressed to about half the compression pressure usual in the Diesel; a small portion of this air being contained

in an auxiliary chamber, which is in open communication with the interior of the cylinder, and which has been heated to a high temperature (by external means prior to starting; or by the heat of the previous combustion, while running), the temperature resulting from the mechanical compression being, therefore, considerably higher in this chamber than in the main portion of the cylinder; the fuel is introduced, at or about the completion of this compression, either directly and entirely into this auxiliary chamber, or through the cylinder and partially into the chamber; and gasified and ignited by the heat of com-

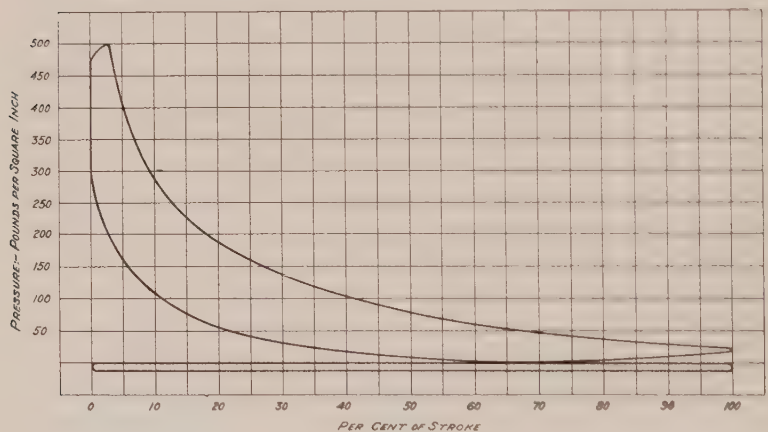


Fig. 2.

pression of the air in the chamber, the combustion taking place more suddenly and with a greater increase in pressure than in the Diesel, and being followed by a more rapid drop.

In engines of both types the maximum ignition pressure is about the same; but the combustion temperature at the commencement of the adiabatic expansion is higher in the Diesel. Figures 1 and 2 show, respectively, typical indicator diagrams of a Diesel and a Semi-Diesel engine.

The two-stroke cycle, as well as the four-stroke cycle of operation is employed in Diesel engines. The selection of the cycle is somewhat arbitrary on the part of the manufacturer, and appears to be governed by the greater or less value placed

upon low cost of manufacture, as against that of efficiency in operation. The rational line of division is affected by so many factors:—the value of money, the cost of fuel, freight rates, the value of floor space, etc.—that it would vary with each locality.

The lower efficiency of the two-stroke cycle Diesel engine is due, primarily, to the power consumed by the scavenging pump, practically none of which is recovered in the working cylinder. This is partially offset by the reduced mechanical losses, due to lighter moving parts. The drop of pressure at the

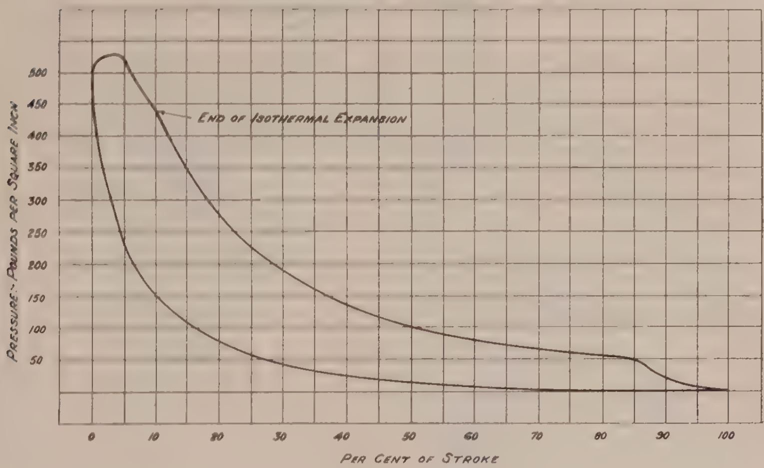


Fig. 3.

release, when the exhaust port of the two-stroke cycle engine is opened, is partially counterbalanced by the "bottom-loop" negative work of the four-stroke cycle.

Figure 3 shows a typical indicator diagram of a two-stroke cycle Diesel engine and may be compared with Figure 1 which is that of a four-stroke cycle engine. Figure 4 illustrates the proportional subdivision of the indicated power developed by four-stroke cycle and two-stroke cycle Diesel engines.

The curves shown in Figure 5 compare the fuel consumption of four and two-stroke cycle Diesel type engines, built by the same American manufacturer.

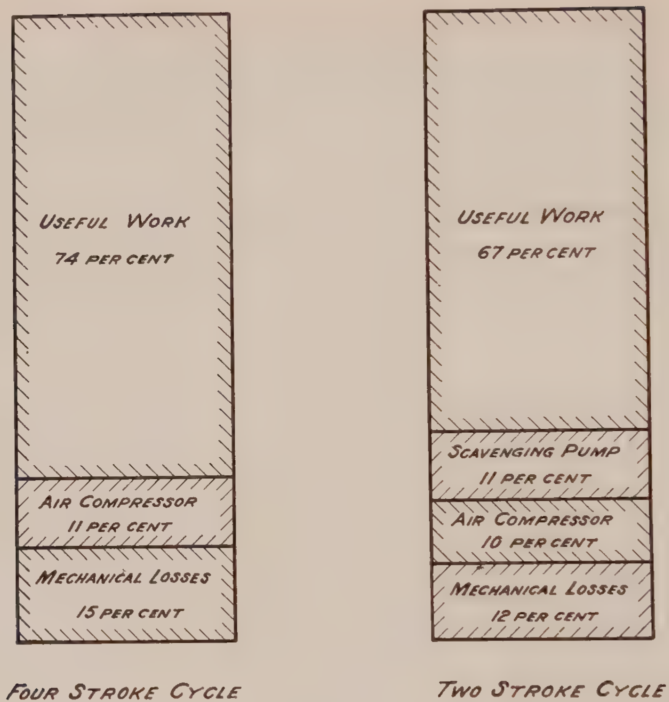

USEFUL WORK
74 PER CENT
AIR COMPRESSOR
11 PER CENT
MECHANICAL LOSSES
15 PER CENT
USEFUL WORK
67 PER CENT
SCAVENGING PUMP
11 PER CENT
AIR COMPRESSOR
10 PER CENT
MECHANICAL LOSSES
12 PER CENT
FOUR STROKE CYCLE
TWO STROKE CYCLE

Fig. 4.

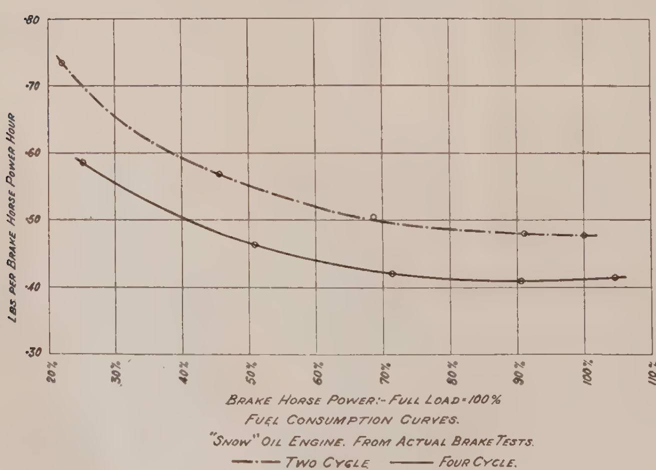

·80
·70
·60
·50
·40
·30
LBS. PER BRAKE HORSE POWER HOUR
20%
30%
40%
50%
60%
70%
80%
90%
100%
110%
BRAKE HORSE POWER:- FULL LOAD = 100%
FUEL CONSUMPTION CURVES.
"SNOW" OIL ENGINE. FROM ACTUAL BRAKE TESTS.
TWO CYCLE
FOUR CYCLE.

Fig. 5.

The older designs of two-stroke cycle Diesel engines, which were provided with cam-operated scavenging and exhaust valves, were run at speeds considerably below those which are usual in the equivalent four-stroke cycle machines, because of the fact that the camshafts of the former revolve at the same speed as their crankshafts; whereas those of the latter revolve at but half of the speed. In later designs, this limitation has been practically overcome by the substitution of scavenging and exhaust ports in the cylinder wall, controlled by the piston, in

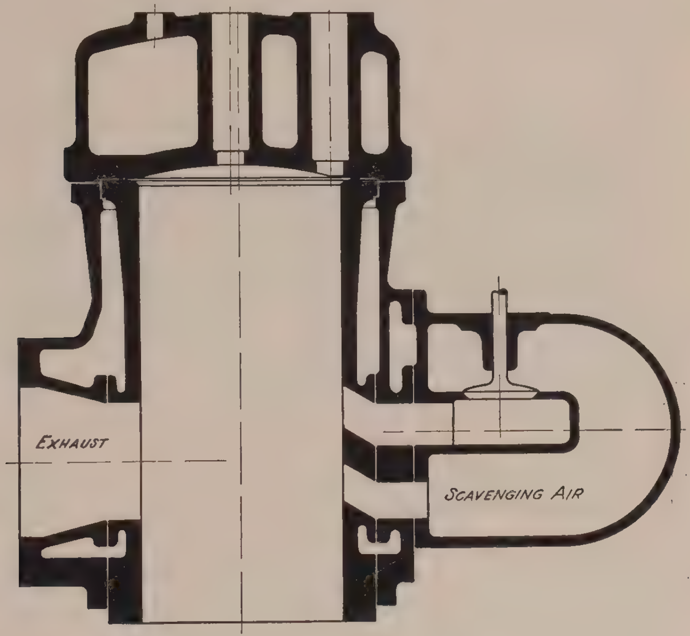


Fig. 6.

place of the heavy valves. This construction, although familiar in gas engine practice, was adopted hesitatingly for Diesel engines, on account of their somewhat high exhaust temperatures, the supposed difficulty of constructing suitable cylinders, and the inefficient scavenging resulting from the fact that the scavenging ports had to be uncovered after the exhaust ports were

open, and therefore re-covered before the exhaust ports were closed.

In Figure 6 is illustrated the construction of a modern two-stroke cycle Diesel engine cylinder, provided with a recently patented arrangement of scavenging and exhaust ports. The exhaust ports are controlled by the piston, as are also the scavenging ports in the lower tier; while the scavenging ports of the upper tier are under the supplemental control of a timed, mechanically operated valve; the lower tier and the mechanical valve open only after the exhaust ports have been uncovered long enough for the pressure in the cylinder to have fallen below the scavenging air pressure; the mechanical valve remains open after the exhaust ports have been closed. This arrangement not only prevents the dangerous blowing back of hot gases into the scavenging air passages; but also ensures more thorough scavenging and the building up of a slight excess pressure in the pure air in the cylinder at the commencement of the compression stroke, thus enhancing its volumetric efficiency and power capacity.

Stationary Diesel engines may be roughly divided into slow speed and medium speed machines. High speed engines of this type are confined to special purposes, such as the propulsion of submarine vessels. Without material variation in piston velocities, the speeds of both classes of stationary engines have been, more or less, selected to conform to the speeds of standard engine-type electric generators. The higher rotative speeds which are becoming general in Europe, have, up to the present, not found favor with any American builder; despite the fact that they appear to be entirely successful. The advantages of a cautious approach to these European speeds are obvious:—lighter weights, smaller space demand, and lower generator costs. The following table compares the speeds of well-known European and American Diesel engines of about 500 horsepower.

	European	American
R. P. M.	240	150 200
Piston Speed	4.15 m. per sec.	3.8 .... 4.15 m. per sec.
" "	815 ft. p. m.	740 .... 815 ft. p. m.
Ratio of diam. to stroke	1: 1.13	1: 1.34 .... 1: 1.28

Within these limits there does not appear to be any appreciable difference in efficiency, reliability, or wear in engines of equally good design and construction.

In Europe there has been a very general adherence to the vertical arrangement of Diesel engines; and, of the few builders of horizontal machines, the majority build vertical engines also. In America both styles have their champions; but, at the present time, the greater number appears to be following the lead of Europe.

At the present time there are comparatively few double-acting engines, of the Diesel type, in operation in Europe; and considerably fewer in America. Practically all of these are horizontal machines. It may be reasonably asserted that there

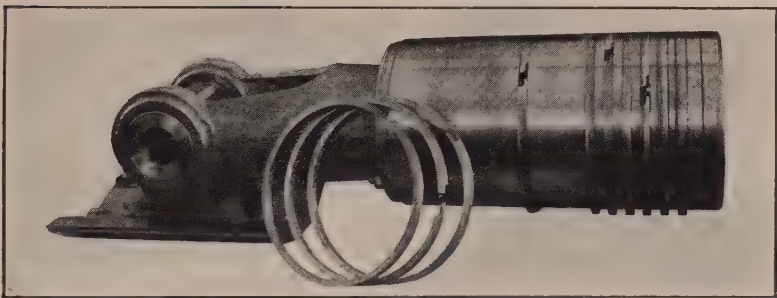


Fig. 7.

is not yet available a sufficiently extensive practical experience with this style of Diesel engine, to warrant the assurance of success in everyday service; and that, in spite of the many advantages which such an engine would possess, especially in large units, its development still lies well in the future.

The Junkers, opposed piston oil engine, which is a development of the well-known Oechelhaeuser gas engine, has not yet been placed upon the open market in the United States; nor has the modified form of this type of engine, invented by H. F. Fullagar, of England, yet found a builder here.

Vertical Diesel engines are being built both with "A" frames, and with enclosed crank-cases. Coincidently with the tendency towards higher speeds, there has developed, in Europe, an increasing inclination towards the enclosed crank-

case; and Sulzer Bros., of Switzerland, recently exhibited, in Berne, a Diesel engine of this construction, of 1000 b.h.p. rated capacity. The enclosed crank-case, for Diesel engines, was adopted in America long before it received any consideration in Europe; and the original American builders still adhere to this style of frame for engines of smaller and medium capacities.

In Europe the use of crossheads and guides is becoming general, for vertical Diesel engines of very large capacities; but American built Diesels have not yet reached capacities and dimensions that would warrant this style of construction, in preference to the simpler and less costly trunk piston. In Figure 7 is shown a combination of piston-body and crosshead, as used in an American-built horizontal engine of the Diesel type.

Practically all Diesel engine cylinders are now built up of a liner, or inner barrel; a jacket, or outer cylinder; and a cylinder head. The space between the liner and the jacket forms the water-jacket. The purpose of this construction is less that of facilitating the renewal of the inner barrel, should it become worn, and of permitting its free axial expansion,—the lack of which possibilities has not been found seriously objectionable in the older designs of Diesel engines,—than to enable the use of the most suitable iron to withstand the temperatures to which the cylinder is subjected, without the manufacturing risks involved by casting a somewhat complicated piece, having great variations in metal thicknesses, of such iron. A typical construction of a four-stroke cycle Diesel engine cylinder, with separate liner, is illustrated in Figure 8.

The registered joint, between the cylinder barrel and the head, prevents the leakage of water from the water-jacket, and of the gases from the interior of the cylinder. The gland-ring, at the lower end, packs against the cooling water; but leaves the liner free to expand axially.

All builders of Diesel engines have learned the necessity of constructing the combustion space of regular form, without pockets or obstructions which would retard the propagation of the flame. In his earliest experiments, Dr. Diesel established the vital importance of this precaution. The effectual cooling

of the cylinder heads, especially the parts adjacent to the fuel valve, and spots where the heat is liable to accumulate, is general; and there are several U. S. patents which cover means for ensuring the delivery of the coldest water to the hottest parts. With practically no exceptions, the heads are made of cast iron, and carry such valves as the type of the engine demands.

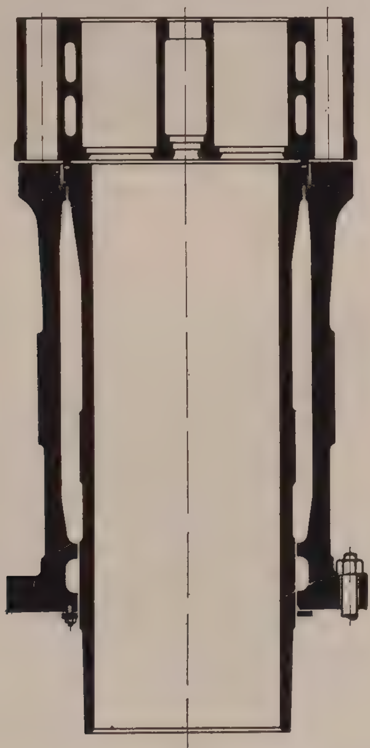


Fig. 8.

The admission and exhaust valves, which are exposed to the high combustion temperatures and to the corrosive action of the fuel, most of which contains sulphur in greater or smaller proportions, are now generally made up of a head of hard cast iron, with a stem of forged steel. In this country Diesel engines are not yet being built in sizes which would make the

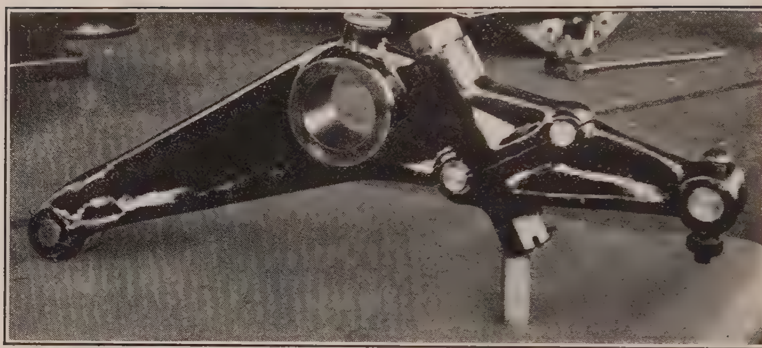


Fig. 9.

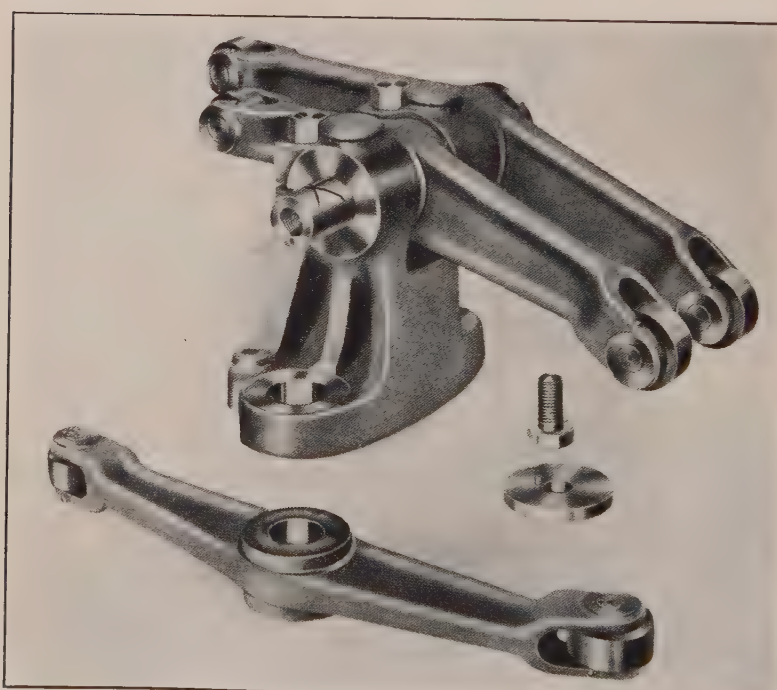


Fig. 10.

water-cooling of the exhaust valves either necessary or convenient; but in the medium sizes, the exhaust valve-stems generally work in water-cooled guides.

Few of the fuel oils in ordinary use are of such character that perfect combustion can be always attained under all conditions of load; it is, therefore, desirable that at least the exhaust valve, which is the most prone to fouling, may be dismantled with the greatest promptness and ease, and with the least disturbance of adjustments. Examples of means to this end are shown in Figures 9 and 10.

The former illustrates the sectional valve lever, as used on Busch-Sulzer Bros.-Diesel engines, in which the valve end of the lever may be disconnected, permitting the withdrawal of the entire valve and cage, without affecting any adjustments.

The latter illustrates the Fulton-Tosi construction, in which the valve levers may be bodily removed from the overhung ends of their shaft.

In the design of Diesel engines more attention has been paid to the correct construction of the fuel atomizers, than to any other single consideration; and with good reason. The atomizer must not only put the fuel into a condition which will ensure its complete gasification and combustion, within the extremely brief period available for these processes; but it must, for each working stroke of the piston, discharge the entire quantity of fuel delivered to it by the fuel pump, and do this in such wise that the ignition and combustion proceed without any explosive characteristics. The experiments carried out on the first Diesel engine proved that the atomizing of the fuel and its introduction into the cylinder, in a manner which would ensure compliance with these requisites, could best be performed by means of compressed air. The elements employed consist of an atomizer, an injection valve, and a nozzle; and these may be arranged to form the "closed" nozzle, as originally developed by Diesel; or the "open" nozzle, as developed by Lietzenmayer. In the former the injection valve is placed between the air and fuel passages entering the atomizer, and the nozzle inlet to the working cylinder; the valve thus separating both air and fuel from the cylinder until the moment of injection. In the latter the injection valve is placed between

the air passage entering the atomizer, and the fuel inlet to the atomizer.

The "closed" nozzle construction shown in Figure 11 is that which has attained the most widespread use. The atomizing elements consist of a series of finely perforated plates, the holes in the alternate plates being offset with reference to each other; followed by a slotted cone, leading to the injection valve,

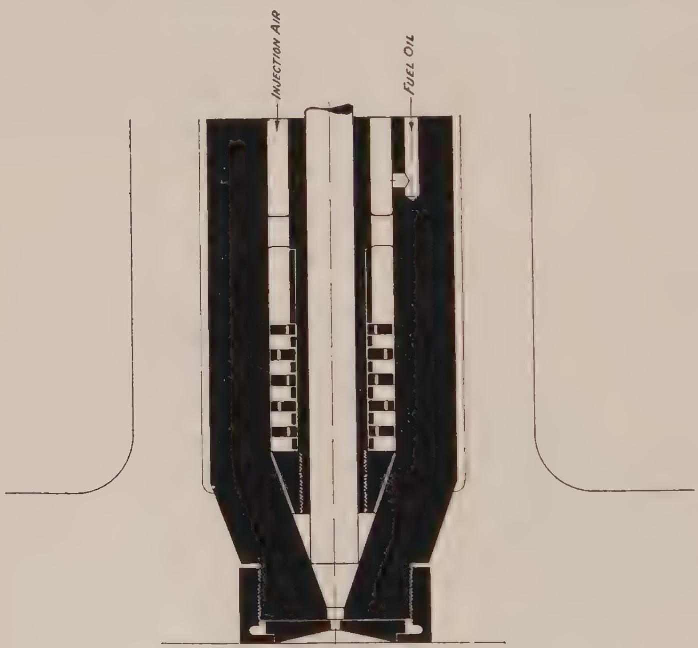


Fig. 11.

and to the nozzle plate at the entrance to the cylinder. Prior to the moment of injection, the requisite quantity of fuel oil for the next working stroke is delivered above the perforated plates, and distributes itself over these; the interior of the atomizer being in open communication with the compressed air. When the valve is lifted from its seat, the air flows in a rapid stream over the plates and through the perforations, carrying the fuel with it and tearing it into fine globules. In its passage through the nozzle plate, after leaving the slotted cone, the mixture of

air and oil atoms is deflected into a flat "umbrella", spreading over the surface of the piston.

The atomizer illustrated in Figure 12 is also of the "closed" type, and is the invention of Mr. Hesselmann, of the Swedish Diesel Engine Co. The typical feature of this is the siphonic arrangement of the passage in which the fuel lies between the time of its entrance into the atomizer, and the opening of the injection valve; the atomizing taking place at the inner upper edge of the siphon passage.

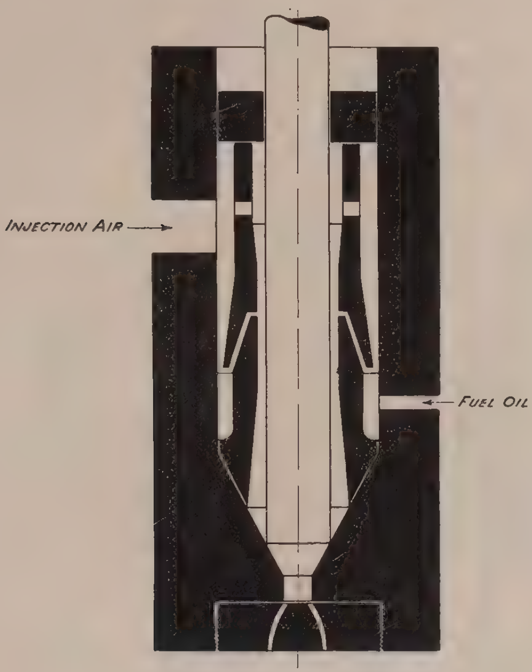


Fig. 12.

The use of the "open" nozzle, as illustrated in Figure 13, is confined, in America, to horizontal engines. In this, the fuel is delivered, by the fuel pump, into a passage which, through a nozzle, is at all times in open communication with the cylinder. The compressed injection air is closed off from this passage, by the injection valve. When this valve is lifted from its

seat, the stream of air scours over the surface of the accumulated fuel, and atomizes it with an action similar to that of a file upon a metal surface. The final atomizing and spreading is performed in the passage through the nozzle, as in the case of the Diesel atomizer.

As the load, carried by a Diesel engine, decreases, and the quantity of fuel injected into the cylinder for each working stroke diminishes, the too rapid injection of the fuel results in a more or less explosive ignition. To avoid this, it becomes necessary to reduce the pressure of the injection air;—i. e., to slow down the injection velocity, by reducing the pressure dif-

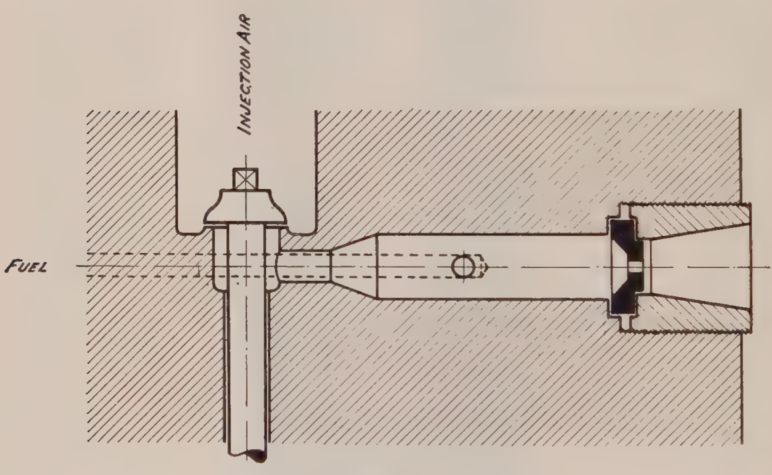


Fig. 13.

ference between the injection air and the air compressed in the working cylinder. In the case of the "closed" nozzle, this is accomplished automatically, to a limited degree; there being less fuel in the atomizer to retard the flow of air, more air is injected and if the free air capacity of the compressor remains constant, the injection pressure falls to correspond to this greater delivery volume. But this self-adjustment is insufficient to accomplish the stated purpose, and has the additional disadvantage that, in spite of the more explosive ignition, the combustion is imperfect, due to the cooling effect of the excess air following the fuel into the cylinder, and it is necessary

either to blow off a portion of the compressed air, or to regulate the volume handled by the compressor. The latter is the general practice, and is effected by throttling the suction of the compressor. This is usually done by hand; but some engines are provided with mechanical means for this purpose, operated by the governor. A device to be utilized in conjunction with

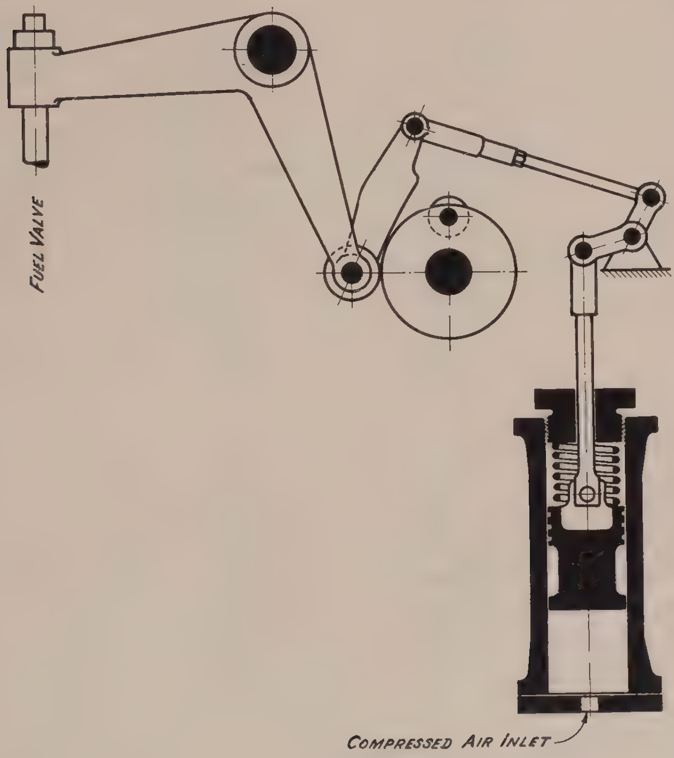


Fig. 14.

that just described, and which has the purpose of still farther reducing the consumption of injection air and, at the same time, diminishing the cooling effect resulting from excess air, and effecting closer speed regulation at very low loads, has been recently patented, and is illustrated in Figure 14. In this device, the fuel lever is provided with a supplementary abut-

ment lever, whose position is varied by means of and to conform to the injection air pressure as adjusted by the governor-controlled throttling of the compressor suction, in such manner that the amount of the opening of the fuel valve, as also the period during which it remains open, are reduced as the air pressure falls, without changing the lead of the fuel admission.

All engines of the Diesel type are started by means of compressed air. To avoid the excessive use of such air, and, at the same time, to simplify the mechanism, it is usual to provide only one or two of the cylinders, of a multi-cylinder engine, with starting valves, and to relieve the compression in the other cylinders until the engine has attained a sufficient speed to effect this comparison without risk of stopping. In small and medium sized engines, the relief of compression is generally accomplished by holding the exhaust valve partially open, which was, formerly, somewhat crudely done by merely slipping a yoke over the exhaust valve lever; but now it is usual to mount the lever hubs on eccentric sleeves, operable by means of hand levers, the arrangement being such that the rotation of the eccentric sleeve simultaneously places the fuel valve out of action and holds the exhaust valve open, and vice versa. This form of compression relief necessitates a separate handling of each cylinder, and does not relieve the cylinders that are used for starting; it, therefore, becomes less convenient, less prompt, and less effective as the size of the engine increases. For the larger sizes of engines, a system has, therefore, been adopted, in which auxiliary cams are used to operate the exhaust valves of all of the cylinders, opening these at the commencement of the compression stroke of the piston and closing them upon its completion, the fuel valves being, meanwhile, out of action until the engine has been accelerated sufficiently, when, by the operation of a single wheel or lever, the relief is cut off all of the cylinders, and the fuel is then admitted to them one at a time.

The construction of the pistons and their accessories, for Diesel engines, has been reduced to an almost uniform basis. In the larger sizes, some builders provide the pistons with separate heads, secured to trunk guides. Plain snap rings, of cast iron, have become universal; these being provided with

ordinary lap joints. The piston rings are usually not dowelled, to maintain fixed relative positions of the joints; except in the case of two-stroke cycle engines in which the rings over-travel ports in the cylinder wall, and it is necessary to prevent the joints from traveling across the openings. When the pistons attain diameters in which the area exposed to the heat becomes so great that radiation cannot be relied upon to prevent excessive

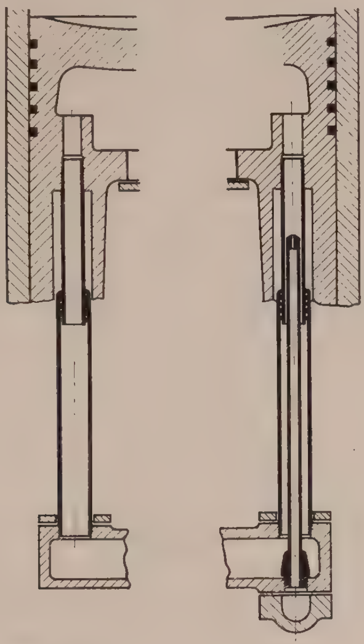


Fig. 15.

temperatures, it is usual to positively cool the piston heads. This is particularly the case in two-stroke cycle engines, in which the pistons are exposed to combustion temperatures twice as often as in four-stroke cycle machines. As a cooling medium, either water, a mixture of water and air, or oil is used. In the last-mentioned case, which has certain advantages where only salt water is available, the oil is re-cooled and used over again. A simple form of piston cooling is illustrated in Figure 15.

Of importance equal to that of the fuel atomizing elements, is the method of and mechanism for the regulation of the amount of fuel delivered to the cylinder, to suit the existing load. The quantity, even at full load, is so minute, that an almost infinitesimal variation will materially affect the speed of the engine. For example, the quantity of fuel oil delivered to a 100-horsepower cylinder, per working stroke, is only 0.0046 litre (0.28 cubic inch) at full load, and 0.0026 litre (0.16 cubic inch) at half load; or a difference of 0.002 litre (0.12 cubic inch) between full and half load. This fuel oil is delivered to the atomizers by means of a fuel pump, having one plunger to serve each working cylinder; or one plunger to

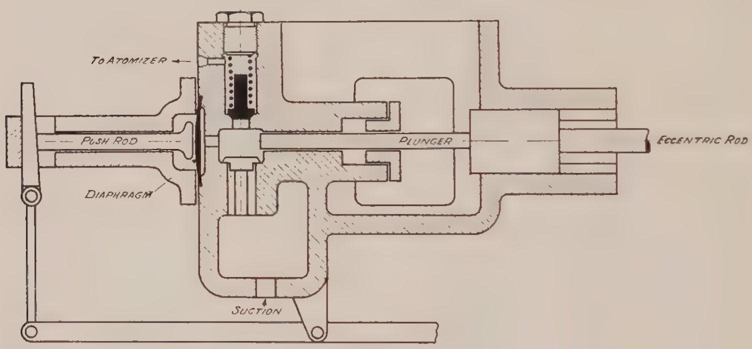


Fig. 16.

serve several cylinders, with a proportioning distributor to equalize the delivery to each to suit the average load conditions. Some of the methods used, to regulate the fuel supply under the control of the governor are:—varying the stroke of the pump plunger; maintaining a constant stroke of the pump plunger, but by-passing back to the suction, during the delivery stroke, a variable quantity of the fuel; or maintaining a constant stroke of the pump plunger, with a constant pump barrel volume during the suction stroke, and varying the pump barrel volume during the delivery stroke. This last is accomplished either by means of an auxiliary plunger, which communicates with the same barrel in which the plunger proper works, and which takes a constant position at all times during

the suction stroke, but a variable position during the delivery stroke; or by means of a diaphragm which forms one wall of the pump barrel, and which takes a constant position at all times during the suction stroke, but is, during the delivery stroke, deflected to a variable extent, against a stop whose

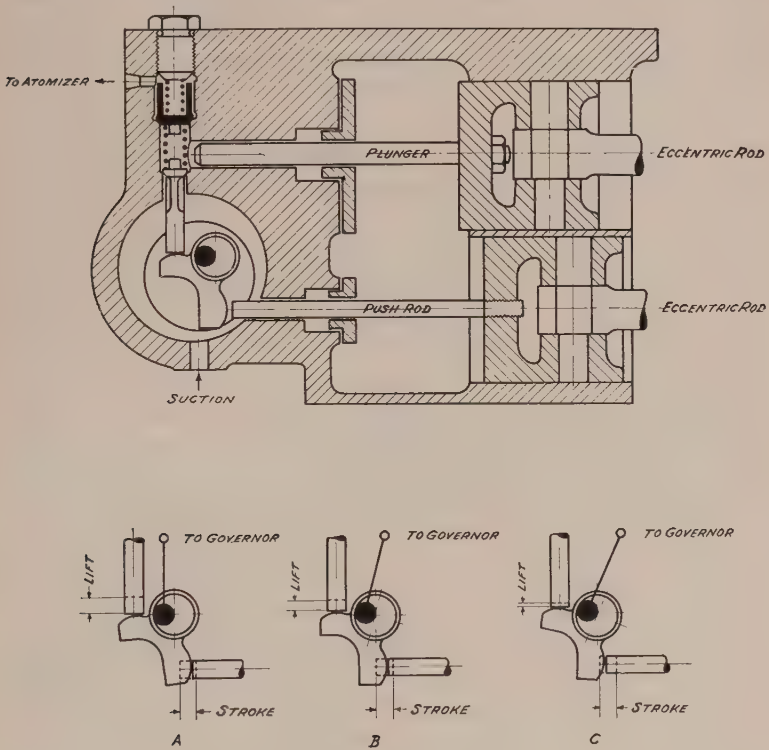


Fig. 17.

position is varied by the governor. This method, as patented by the Fulton Iron Works, is shown in Figure 16.

The method that has become general in Europe; but the use of which in America is still restricted to the owners of the patents, and their licensees, is the second-mentioned, one arrangement of which is illustrated in Figure 17, in which the by-passing is accomplished by holding open the suction valve of the pump, during a portion of the delivery stroke.

Both the plunger and the push-rod have constant strokes; but the action of the bell-crank, operated by the push-rod, is varied by its eccentric mounting, which is rotated under governor control; so that the suction valve of the pump is held open during a longer or shorter portion of the delivery stroke of the plunger. Diagram "A" shows the parts in no-load position, the suction valve being held open almost throughout the entire delivery stroke; "B" and "C", respectively, show the parts in mean and full-load positions.

The pressure of the air, used for atomizing and injecting the fuel, varies with the type of the engine and the proportionate loading. In Diesel engines this pressure ranges from 35 or 40 atmospheres at no load, to 65 or 70 atmospheres at full load; a slight variation being desirable to suit the character of the fuel oil. This air is generally compressed by a three-stage air compressor, integral with or directly coupled to the engine. To avoid lubrication difficulties and the danger of explosion of lubricating oil gases, as well as to reduce the dimensions and power consumption of the compressors, the compressors require very thorough water cooling, and the provision of ample inter- and after-coolers. Single-acting compressors, with the trunk pistons arranged in echelon, have become general; as also have automatic valves of very limited lift. As previously described, the capacity and delivery pressure of these compressors are adjusted by throttling the low-pressure suction.

The main bearings of horizontal Diesel-type engines are generally constructed similarly to those of horizontal gas engines, with at least partial adjustability; whereas adjustable bearings have practically been abandoned in the modern makes of vertical engines, in favor of rigid bearings of such ample surface and provided with such efficient lubrication that their wear is negligible. The advantages of the latter construction are obvious in the case of multi-cylinder engines, such as vertical engines usually are, in which a number of bearings are in line. It has been found difficult to adjust such bearings without removing the shaft, as the touch alone is an insufficient indication of pressure, where the parts are heavy. The lower shells of these rigid bearings are semi-cylindrical, and can be rolled out without removing the shaft. These considerations

have led to the adoption of a continuous, rigid bedplate, carrying all of the main bearings in carefully machined seats.

The lubrication of the working cylinders is performed by a positive lubricating pump, having one or more plungers to serve each working cylinder, the oil entering the cylinder in several places,—usually four to six. For the cylinder lubrication it is desirable to use an uncompounded neutral mineral oil, with a flash-point not lower than 180° C. (350° F.), a

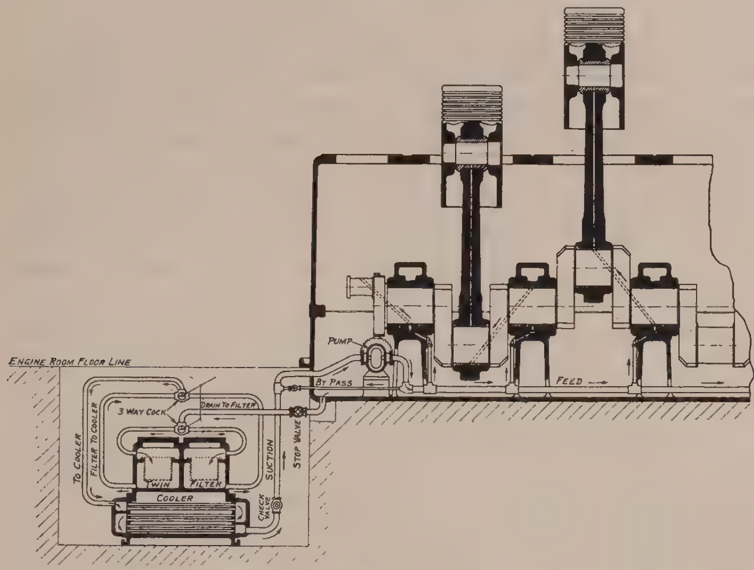


Fig. 18.

viscosity as high as the lubricating pump will handle reliably, and the characteristic of retaining a high degree of viscosity when hot; the function of this oil being not only to lubricate, but also to serve as a packing medium, by forming a seal between the piston rings, against the leakage of air or gases. The compressor pistons are generally lubricated by a pump or by high pressure sight-feed lubricators, and use an oil similar to that for the working cylinders; except that a slightly lower viscosity and higher flash-point are preferable.

In vertical engines, the prevailing method of lubricating

the bearings and pins is the forced feed system; although some builders still adhere to ring oiling for the main bearings, and centrifugal oiling for the pins. A typical arrangement of forced feed lubrication is shown in Figure 18. The oil is maintained in continuous circulation by a positive displacement pump, which delivers it to the main bearings, from which it passes through passages in the crankshaft to the crankpins, and thence through the hollow connecting-rod to the piston pins. The spill from the bearings and pins flows back to a filter and cooler, from which it is again drawn by the pump. With this arrangement all moving pipes or slings are obviated. For this method of lubrication almost any high grade, neutral, uncompounded mineral engine bearing oil is suitable; it should not be too light, and, in service, its temperature is permitted to rise to 50 or 60° C. (120 to 140° F.), according to its viscosity.

To those accustomed to steam engines, or, still more so, to steam turbines, the consumption of lubricating oil by a Diesel engine usually appears high; but this is the only operating expense on account of which the Diesel engine can possibly be accused of extravagance. This consumption averages 0.3 litre (0.07 gallon) per hour per 100-horse-power engine rating. Of this about 20 to 25 per cent is used in the cylinders.

The exhaust gases leave the engine cylinders at temperatures reaching 350 to 370° C. (670 to 700° F.) at full load; but the temperature rapidly falls with decreasing loads. To render the operation of the engine safe and comfortable, it is usual to water-jacket such portions of the exhaust headers and pipes as the operator might come in contact with. Through these jackets is circulated a portion of the water which has already done duty in other parts of the engine, where the rise in the temperature of the water must be maintained at a lower point. The exhaust gases from a properly designed, adjusted, and operated Diesel engine are invisible, and remarkably free from combustible constituents; of which the following table is an example. This table shows composition of exhaust gases taken from a Busch-Sulzer Bros. Diesel Engine, in regular operation; over mercury, to avoid absorption of any constituent gases; and analyzed by Drs. Harper and Bailey, Professors of Chemistry, at the University of Texas.

Tests	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Load	3.5%	26.0%	52.0%	75.0%	102.0%	113.0%
Oxygen	18.42%	16.03%	14.95%	14.70%	9.93%	8.93%
"Illuminants"	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Monoxide	0.00	0.00	0.00	0.00	0.00	0.00
Methane	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	1.50	3.05	3.92	4.70	6.46	8.40
Nitrogen and Water Vapor	80.08	80.92	81.13	80.60	83.61	82.67
	100.00	100.00	100.00	100.00	100.00	100.00

The majority of crude and fuel oils contain appreciable quantities of sulphur, which, if not over 1½ per cent, will not seriously affect any engine parts other than the exhaust passages, and, to a less degree, the exhaust valves; but which, even in small amounts in combination with the hot vapors of the water of combustion, will attack the exhaust pipes near the engine. For this reason, these pipes are made of cast iron, and the use of steel for this purpose is avoided.

The noise of the exhaust is muffled by the same means as are in common use with gas engines; but concrete exhaust muffling chambers have been found undesirable, on account of the disintegrating effect of the hot oil vapors, which may temporarily pass from the cylinders, due to some mal-adjustment of the valve gear.

Although almost all forms of carbonaceous and hydrocarbon fuels, from powdered coal to gas, have been tried experimentally in Diesel engines, commercially successful operation has been confined to liquid fuels,—more particularly to mineral oils and coal tar. And in the United States the relative value of tar is so high, on account of the marketable products obtainable from it and its use for roofing and similar purposes, that there has been no inducement to use it for Diesel engine fuel, in preference to the cheap petroleum fuels. It was for this reason alone, that one large gas company, after for some years successfully using the tar from its own works as fuel in its Diesel engines, changed to oil; finding it possible to sell the tar for more than the cost of the oil.

There does not appear to be any limitation to the possibility of using mineral oils in Diesel engines, from the heaviest

crudes to refined kerosene; but commercial and practical considerations tend to give preference to fuel oils ranging between 24° and 36° Beaume. The available supply of these fuels is large in proportion to the demand for them, so that they may generally be purchased at prices as low as, or lower than those of crudes, from which the valuable lighter and heavier constituents have not been abstracted. The heat value of petroleum oils is rarely lower than 10500 cals. per kg. (19000 B.t.u. per pound), high value. Based upon weight, the heat value decreases as the gravity becomes heavier; but based upon volume, the reverse is the case, although to a less degree. For instance: a 15° crude of 10000 cals. per kg. (17900 B.t.u. per pound), has a heat value of 9650 cals. per litre (144000 B.t.u. per U. S. gallon); while a 39° distillate or fuel oil of 10900 cals. per kg. (19500 B.t.u. per pound), or 9 per cent higher, on a weight basis, has a heat value of 9050 cals. per litre (135000 B.t.u. per U. S. gallon), or 6 per cent lower, on a volume basis.

Fuel oils, for use in Diesel engines, should contain the lowest proportions of the following impurities, compatible with the prices demanded:

Water:—because it is charged for at the fuel oil price; it reduces the efficiency of the engine; it increases the maintenance costs; and it has a detrimental effect upon the regulation. More than one-third of one per cent of water should be considered excessive; and, if fuel containing more than this has been accepted, the water should be settled out, by heating the oil by means of a steam coil.

Sulphur:—if in excess of 1½ per cent, the combination of the sulphurous fumes with the vapors of the water of combustion, will corrode and pit the exhaust valves and seats, and rapidly eat out the exhaust piping.

Ash:—a comparatively minute percentage of entirely noncombustible matter in the fuel causes an accumulation on the oily cylinder walls, between these and the piston, which will result in excessive wear.

Asphaltum:—this much abused term is susceptible to so many and various interpretations, that it has no definite significance. Nor has the method for its determination been standardized. The various chemical and mechanical (penetration)

determinations have little or no bearing upon the real issue under consideration here; viz., the complete combustibility in a Diesel cylinder under the conditions existing in it and within the available time. A comparison of results obtained in actual use for the above purpose, with oils containing a substance, other than ash, which will not volatilize under certain definite conditions, appears to be the best guide as to the proportion of this substance which will render necessary an excessively frequent cleaning of the cylinder and its adjuncts. Several years of careful observations and records have induced the oldest Diesel engine builders in this country to adopt, for such comparisons, the percentage of residue remaining after the sample of oil has been gradually brought to a temperature of 300° C. and then subjected to this temperature for 120 hours, in a closed furnace, in which combustion does not take place. Under this treatment the sample is reduced to practically constant weight. It has been determined that, so long as this residue is less than 10 per cent of the original weight of the sample, unreasonably frequent cleaning is not necessary. This percentage is equivalent to anywhere from 7 to 30% of "Asphaltum", according to the various methods of determination in use. If the fuel oil contains more than the above-mentioned 10% of residue, its use must be guided by the relative cost of the oil, and the cost and inconvenience of labor and stoppages required for the more frequent cleaning. The form of the atomizer does not appear to have any bearing upon this question, as the substance does not become objectionable until after the fuel has entered the cylinder and its more volatile constituents have become gasified; although it may render the fuel so "heavy", that warming is necessary to enable the oil to flow to and be handled by the fuel pump of the engine.

Figure 19 illustrates the consumption of fuel oils of widely varying gravity, in the same engine.

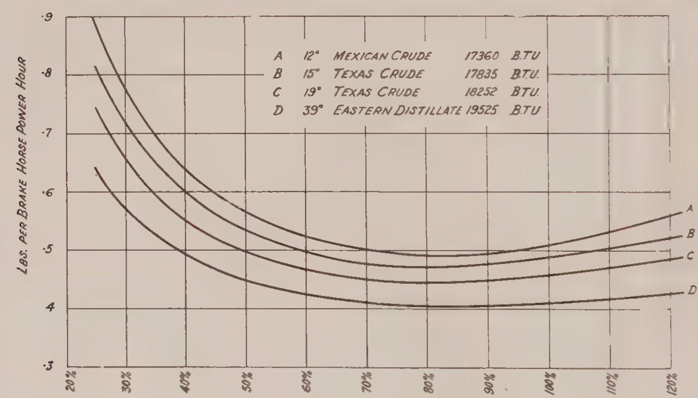
In the following pages are mentioned and briefly described several Diesel type engines, built in the United States.* Although representative of the general development of this type of engine, in this country, several more or less known makes

* The editors have been compelled to omit cuts of the various engines mentioned, due to limitations of space.

are not shown, due to the unfortunate attitude of the builders. The writer wishes, here, to express his indebtedness to the courtesy of those builders who are referred to by name, in this paper.

"Snow" Oil Engine, built by the Snow Steam Pump Works, of Buffalo, New York. This engine is of the builder's own design, based upon his experience in the manufacture of large gas engines.

The air compressor and scavenging pump are mounted on the side of the frame, and driven by a drag-crank on the end of the crankshaft. The regulation is accomplished by varying



BRAKE HORSE POWER:- FULL LOAD=100%
FUEL CONSUMPTION CURVES
"ALLIS-CHALMERS" SINGLE CYLINDER OIL ENGINE.

Fig. 19.

the stroke of the fuel pump plunger, by means of a sliding wedge, operated by the governor. This engine employs a modified type of "open" nozzle.

Allis-Chalmers Oil Engine, built by Allis-Chalmers Manufacturing Co., of Milwaukee, Wisconsin. This engine is designed under the Lietzenmayer patents, using the "open" type of fuel nozzle of that name.

The air-compressor is mounted on the side of the frame, and actuated from the crankshaft. The regulation is performed by varying the effective stroke of the fuel pump plunger, under governor control. A gravity oiling system, with filtering arrangements and pump, is used for all important bearings;

the lubrication of the cylinders, and in special cases that of the exhaust valve stems also, is performed by a force feed oil pump. A maximum load and a no-load indicator diagram of this engine are shown in Figure 20.

Four-cylinder, vertical, four-stroke-cycle Diesel-type oil engine built by McIntosh & Seymour Corporation, of Auburn, New York. These engines are built in accordance with the designs of and under the sole rights to the U. S. patents of the Swedish Diesel Engine Company, of Stockholm, Sweden.

These engines use the Hesselmann patent fuel atomizer, described in an earlier part of this paper; in conjunction with the by-pass type of fuel regulation, under license from Busch-

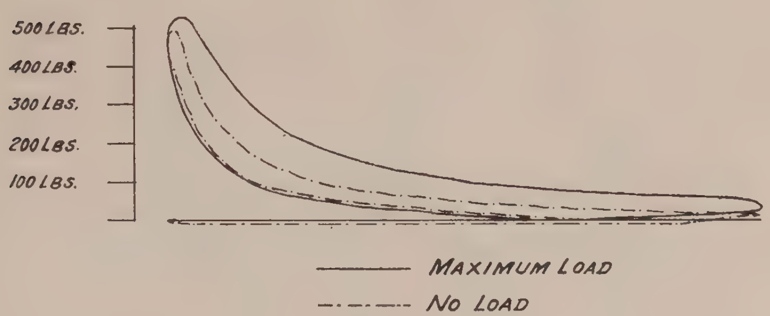


Fig. 20.

Sulzer Bros.-Diesel Engine Co. The air compressor forms a miniature "A" frame unit, directly coupled to one end of the crankshaft, and conforming in its general appearance with the working cylinders and their frames. The arrangement of air tanks is unique and has the object that the tanks may be manipulated from the engine platform, instead of, as is usual, from the floor.

Fulton-Tosi oil engine, built by Fulton Iron Works, of St. Louis, Missouri, under license from Franco Tosi, of Milan, Italy. The engine is of the "A" frame type, and employs the variable pump barrel volume type of fuel regulation, with governor controlled diaphragm, as illustrated in Figure 16. Full load indicator diagram, from one cylinder of a three-cylinder engine, is shown in Figure 21.

Dow-Willans Diesel type oil engine, built by Dow Pump and Diesel Engine Co., of Alameda, California; under license from Willans & Robinson, of Rugby, England. This engine is of the "A" frame type, with a Reavell air compressor directly coupled to the end of its crankshaft.

Fulton Diesel-type oil engine, built by Fulton Manufacturing Co., of Erie, Pennsylvania. It is of the "Marine" crank-case style, with a directly driven air-compressor, mounted upon the crank-case, symmetrically with the working cylinders.

This manufacturing company confines itself, at the present time, to units of 100 horse-power and under, of the full Diesel principle.

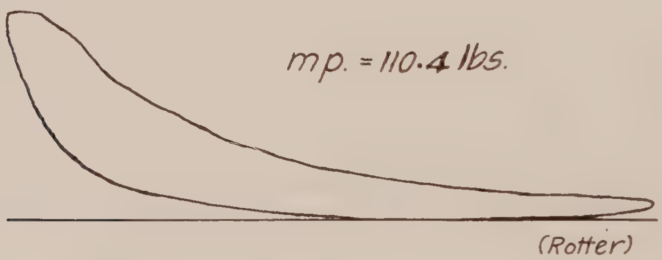


Fig. 21.

"The Harris Valveless Engine", built by Southwark Foundry & Machine Co., of Philadelphia, Pennsylvania; under the "Harris" patents.

The engine is of the vertical, two-stroke cycle type, with stepped pistons performing the double function of scavenging pumps and low pressure stages of the air compressor, the intermediate and high pressure stages of which latter are arranged in line with the working cylinders.

Figure 22 shows a partial section of a 500-horsepower, 200 r.p.m. Diesel Engine, built by Busch-Sulzer Bros.-Diesel Engine Co., of St. Louis, Missouri.

This company is the continuation of the original Diesel Motor Company of America, in combination with Sulzer Brothers, of Winterthur, Switzerland, and the late Dr. Diesel. The engine illustrated is of the four-cylinder, vertical, four-stroke cycle, enclosed crank-case type; with the air compressor directly

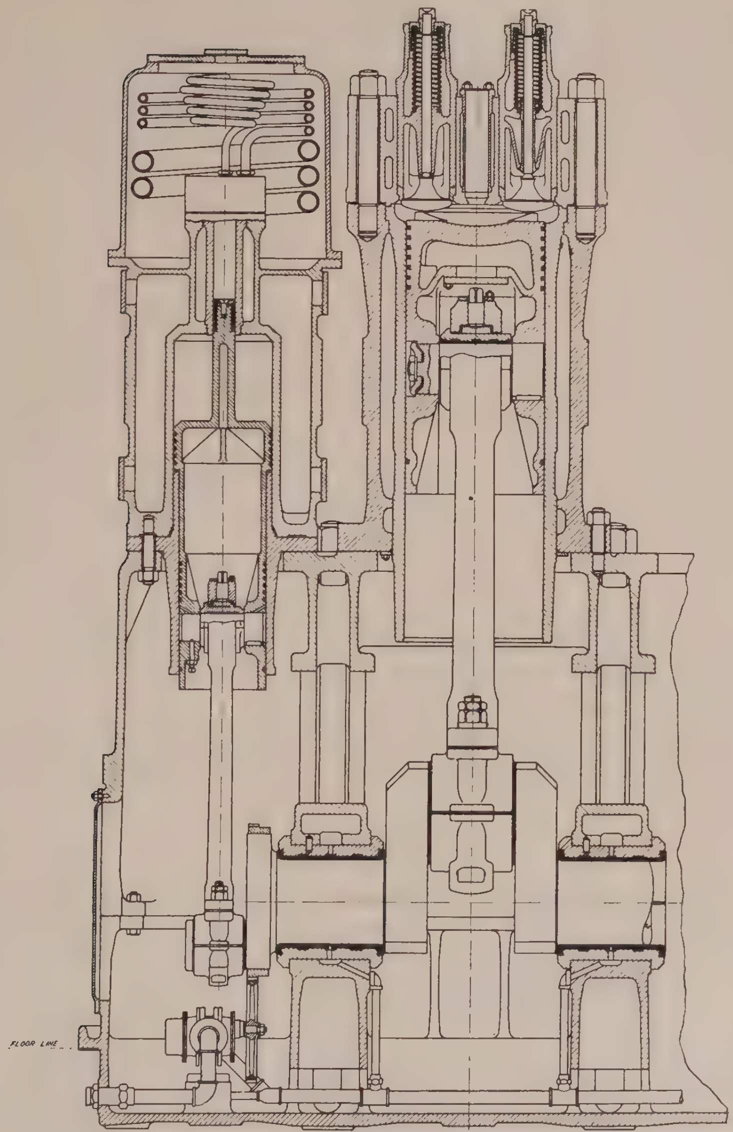


Fig. 22.

driven from the crankshaft, and mounted on the crank-case symmetrically with the working cylinders.

The engine is provided with positive pressure lubrication, the filter and cooler for which are placed in an accessible pit formed at the end of the foundation, the arrangement of the oiling system being shown diagrammatically in Figure 18.

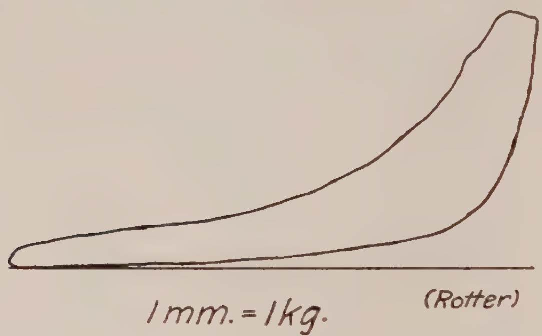


Fig. 23.

The engine is provided with cam-operated compression relief, automatic compressor pressure regulation, automatic injection regulation, and piston cooling. Figure 23 is a full-load indicator diagram taken from this engine.

This diagram clearly shows the end of the isothermal expansion, which is characteristic of the true Diesel engine.

DISCUSSION

Mr. Kennedy. **Mr. H. J. Kennedy** opened the discussion by stating that the main factor in Diesel engine use is the cost. Costs had been reduced during the last two or three years and he asked if any part of the paper brought out the costs of construction.

Mr. Williams. **Mr. Fred L. Williams** stated that the cost was about $45.00 per horsepower.

Mr. Seshasayee. **Mr. R. Seshasayee,*** Assoc. A. I. E. E., remarked that the operating costs of a Diesel engine were about the same as a Blackstone engine and for a 50-horsepower engine were about one cent per horsepower-hour and about seven-eighths cent per horsepower-hour for a hundred horsepower engine—one cent per horsepower-hour being a good rough average.

* Trichinopoly, South India.

Mr. Youens.

Mr. A. V. Youens† stated that they had in operation at Palo Alto, California, a 300-horsepower, four-cylinder, four-cycle, horizontal Diesel engine, manufactured by the Koerting Diesel Engine Co., Germany. They used fuel oils, the same as burned under their boilers, of as low a gravity as 14 degrees Baumé. They had tried Star oil, but found that the operation was but little if any better than with the crude oil. About five gallons of zerolene lubricating oil are used per day, many oils having been tried with varying success. Considerable trouble had been encountered through blackening of the piston and carbon or asphaltic deposits under the piston rings which results in the pistons seizing. The reason is thought to be faulty lubrication. The Bosch Magneto Co. using the same type of engine have had a similar experience.

In order to avoid this trouble and possible inopportune shut down they make it a practice to shut down every Saturday and remove the deposit of carbon from one piston. Whether this piston removal is necessary or not is a question. The valves are removed for cleaning once in two weeks.

Mr. Babcock.

Mr. A. H. Babcock,‡ Mem. A. I. E. E., remarked that it was a well-known fact that ships propelled by Diesel engines have reached this coast from Denmark without having been compelled to stop for repairs or removal of pistons, and he wondered what might be the reason for the frequent removal of pistons in the Palo Alto engine.

Also he asked for further information about the amount of lubricating oil used and said he would also like to know the reason for the selection of the Diesel type of plant for the City of Palo Alto.

Mr. Youens.

Mr. Youens replied that the best running conditions and the proper handling of the engine had probably not, as yet, been determined, and this might in part account for the trouble. Experience would, no doubt, in time eliminate at least a part of their difficulties. The engine left Germany just before the opening of the present war, and in consequence they had not been able to get instructions from the factory, which would in all probability straighten them out.

The engine cost $14,360, the generator $2200, and the complete installation $30,000, including the switchboard, panel, foundations, etc.

The foundation is somewhat unique, it being a pier surrounded by an annular space filled with a crushed cork, which construction is intended to eliminate the vibration in the building. As a matter of fact, there is very little vibration even of the foundation itself.

Mr. Youens stated that they had changed the kind of oil often and were not prepared to give exact figures, but that they used about five gallons of zerolene per day. The fuel consumption on full load was 0.385 lbs. of oil per b.h.p. per hour.

As to their reasons for selecting a Diesel engine, there were a number of peculiar conditions. Their steam plant had been operating non-condensing, being too far from the bay to secure the necessary con-

† Asst. City Engr., Palo Alto, Calif.

‡ Cons. Elect. Engr., Southern Pacific Co., San Francisco, Calif.

Mr. Youens. densing water to operate a condensing plant; therefore, it would have been necessary to install a cooling tower if that type of plant had been decided upon, at a cost beyond the bond issue voted for the construction of the plant.

At one time it had been decided to use a gas-producer plant and a contract had in fact been signed, but due to some difficulties within the contracting company, the contract fell through. Upon further examination of the conditions, the decision was made in favor of the Diesel engine.

The existing conditions of operation at the plant are as follows: The Diesel engine alone takes care of the city's requirements for about 21 hours per day; during the three hours of peak load it is necessary to assist with the steam plant.

The exhaust gases of the Diesel engine are conducted, by way of exhaust silencers or mufflers, to the steam boilers, the idea being to utilize the exhaust heat of the Diesel engine as much as possible towards the maintenance of steam pressure in the boiler. Except for the three hours' daily peak load, the oil burners are operated but two or three times a day, for part of an hour, in order to keep up enough steam in one boiler for atomizing, so as to be able to start the others in case of an emergency shut-down of the Diesel engine, and for the above-mentioned peak period. This precaution is necessary to guard against possible interruption of all services, and especially that of municipal fire protection.

Paper No. 126

THE BOILER OF 1915.

By

ARTHUR D. PRATT
Asst. to Advisory Engineer, The Babcock & Wilcox Co.
New York, N. Y., U. S. A.

The Committee in assigning this subject has certainly been generous in the scope allowed. It is entirely too large to be covered in any paper limited as this must be, where it is only possible to indicate modern tendencies in boiler practice. Further, in the present state of the art, such a paper must of necessity deal not so much with the design of the boiler proper as with furnace design, methods of operation, and the like, and possibly a better title would be "Boiler Practice of 1915".

Steam generating apparatus, as it is in general use today, represents nothing essentially new. The developments in recent years, in so far as the boiler proper is concerned, are rather in the line of refinement of design than alteration. The design of the representative boilers today is not radically different from the design of those that have been offered for twenty years past. There are of course numerous boilers offered from time to time as being entirely new in the art, but upon examination practically all such boilers will be found to conform in general design to something that has already been tried and, in most instances, discarded for various reasons as being unsatisfactory.

Boiler construction has of course improved, but changes making for safety in operation are not to be confused with changes of design. The modern tendency toward the use of high pressure steam has been the prime factor in causing constructional changes. Further, there is a tendency toward standardization of boiler construction by legislation in various communities. Such legislation was at first widely scattered and hardly efficient, but within the last few years there has been a general

effort on the part of communities to pass laws governing construction and operation of steam generating apparatus. The Commonwealth of Massachusetts was the first to pass such a comprehensive law in this country. Fortunately, this law was of such a character that it could be copied by other communities,

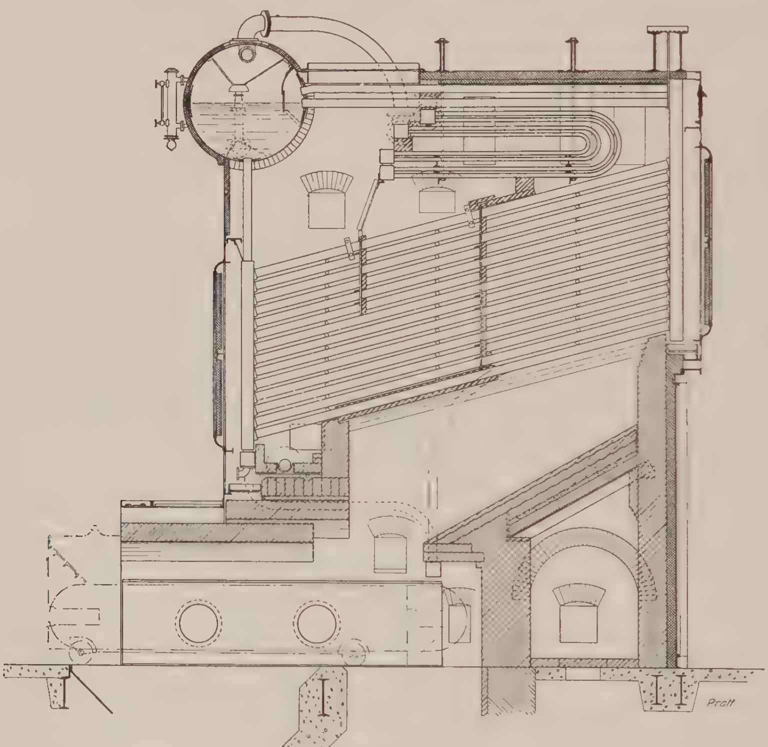


Fig. 1.

and it has been the basis of practically all such legislation. In passing, it is of interest to note that a committee appointed by the American Society of Mechanical Engineers is, at the present time, preparing a set of rules and regulations covering the construction of steam boilers with the idea of ultimately having its recommendations adopted as a standard law throughout the country. The importance of such a uniform law cannot be overestimated, as under it the users of steam boilers would be protected to an extent hitherto impossible.

To treat the subject of modern boiler design in full would necessitate the illustrating of the various types of boilers built by different manufacturers. Should this be attempted, in order that there might be no partiality, it would be difficult to say where to stop, and the number of illustrations necessary would far exceed the prescribed limits. Further, the number of radical changes in actual boiler design that could be shown would, as has been stated, be negligible. Therefore but a few of the most modern designs are shown.

It is evident upon inspection that these illustrations, while they represent some advance in the art, are in reality but slight modifications of designs that have been manufactured and used for years.

Fig. 1 shows a boiler combining the stationary and marine type of Babcock & Wilcox construction. Boilers of this design have been installed in units of 1200 rated horsepower and are giving eminent satisfaction as to efficiency and capacity.* The furnace is of an efficient form, and with the class of coals best suited for use on chain grate stokers, is, in the opinion of many engineers, the best in the art in so far as producing smokeless combustion is concerned.

Fig. 2 shows a boiler that is coming into general favor in England and on the Continent. Here, too, the marine type of drum, namely, a cross drum, is used. The distinctive feature of this boiler is the inclusion of an economizer as an integral part of the unit.

Fig. 3 represents an essentially different design from Figures 1 and 2, though it is simply the combination of two partial units of a well known boiler type. The distinctive feature here is the form and size of furnace made possible by the boiler design, and the very good performance of these boilers, to which reference will be made later, is directly attributable to the furnace. Units of this class have been built in sizes above 2300 nominal rated horse power.

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* The figures for rated horse power given herein are based on 10 square feet of heating surface per horse power. All figures for capacity generated are on the basis recommended in the boiler code of the American Society of Mechanical Engineers, namely, 1 horse power equals 34.5 pounds of water evaporated from and at 212 degrees per hour.

Because of the limitations noted, it is possible to thus bring out but a few features of modern construction. The endeavor will be made, however, to describe the essential features common to all of the representative boilers of today.

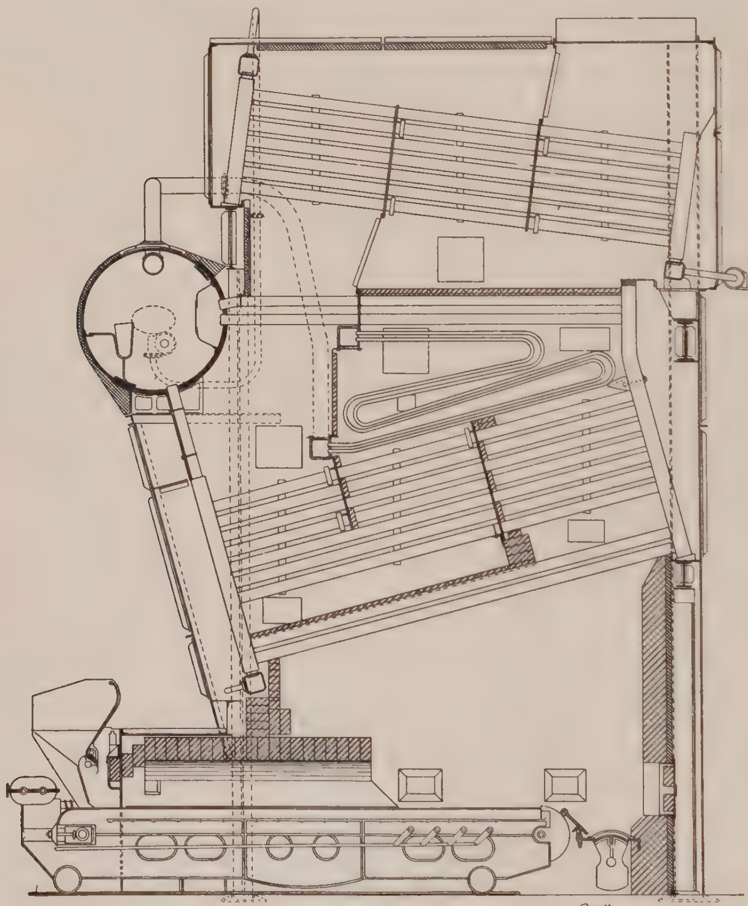


Fig. 2.

While the size of individual boiler units is not primarily a factor in boiler design, it would seem logical in this connection to consider the general tendency toward increased size of units.

Ten years ago, boiler units of 500 or 600 horse power were looked upon as approaching the practicable limits. Today such

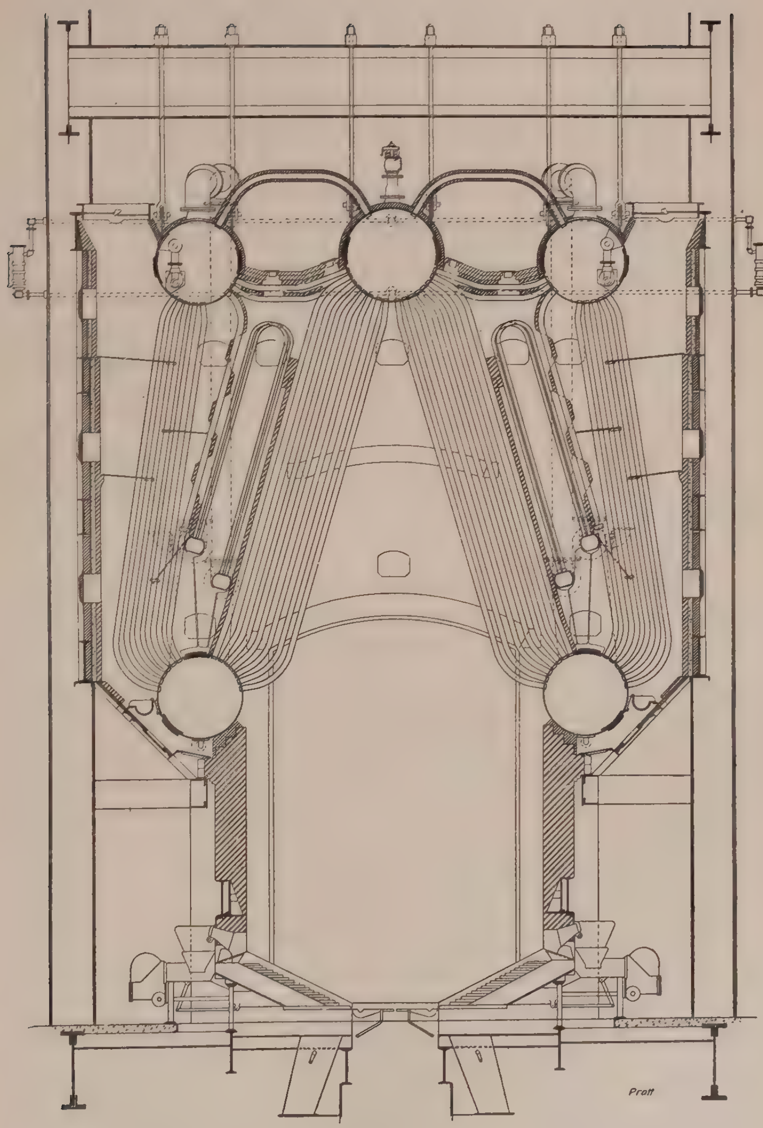


Fig. 3.

units are common, and a number of installations have been made that are composed of units of twice this size. Probably the largest units in operation today are the Stirling boilers installed at the plant of the Detroit Edison Company.* These boilers contain 23,600 square feet of heating surface each, are nominally rated at 2360 horse power and are developing, under ordinary operating conditions, 4000 horse power and over. That units of this size are considered practicable is perhaps best shown by the fact that the Detroit Edison Company has installed thirteen boilers of this size.

The Commonwealth Edison Co. of Chicago has installed a number of units containing 12,200 square feet of heating surface, each nominally rated at 1220 horse power, and these boilers have given good service over a long period of operation.

While units of the size described are not as yet common, their use in some of the foremost power stations in the world certainly indicates a tendency toward an increase in the size of the units for central station work. The increase in the size of boiler units is, perhaps, a logical result of the increase in size of generating sets, but, aside from this, there are features of economy resulting therefrom which cannot be overlooked. There is an increase in the thermal efficiency of the boiler through minimizing the radiation losses and through the higher temperatures and better mingling of the gases possible in the larger combustion chambers. From the financial standpoint, while the cost per unit of power may be no less than in small units, the saving possible in floor space, cost of setting, suspensions, valves and the like, represent a very appreciable item. That there is an appreciable labor saving in the use of large units has been demonstrated in actual plant operation.

The size of the boiler unit permissible will depend primarily upon the size of the prime movers, proper consideration being given to the question of reliability of the steam generating apparatus, the necessity for spare units and factors of a like nature. American practice differs considerably from European practice in respect to the number of units of a given size ordinarily allowed for a given kilowatt output, due to the fact that in the United States ordinary rates of driving boilers are far beyond

*These boilers are similar to that shown in Fig. 3.

the rates ordinarily practiced in European countries. A specific instance of the tendency in this country toward larger units, both boiler and prime movers, is given later in the discussion of modern boiler capacities.

The two most marked tendencies of modern boiler room practice in this country are, without question, the effort to secure higher efficiencies and to obtain, from a given heating surface, greater capacities. From a purely engineering standpoint, the efficiency is of the greater importance. Operating engineers, while not in any sense overlooking the efficiency, are giving the greater attention to the possibilities of high capacities. Inasmuch as increased economies have accompanied increased capacities, the efforts have resulted in a distinct advance in the art.

The factors that have brought about increases in efficiency and capacity are so closely correlated that it is difficult to discuss them separately. Regardless of this, an endeavor will be made to divide the factors, up to a certain point, considering the efficiency aspect first.

For a long time, engineers in general were apparently devoting practically all of their efforts toward securing an increase in the efficiency of prime movers, and, in endeavoring to secure fractional savings along these lines, were overlooking the possibilities of much greater savings that might be accomplished in the boiler room. It was not until what was considered the maximum practicable efficiency of prime movers had been reached that the proper attention was given to the boiler room section of the steam plant.

The factor having the greatest bearing on modern high efficiency is unquestionably the improvement in furnace design. The heating surface of the properly designed steam boiler of today possesses the inherent ability to absorb heat economically. Under such conditions the question of boiler efficiency becomes in reality a question of economical combustion. With hand fired furnaces, it is obvious that any increase in efficiency must be due to improvement in furnace form, for the ability to properly shovel coal into a furnace cannot have changed appreciably. Naturally, with this class of firing, the increased efficiency has been relatively small.

In stoker fired furnaces, the increase in efficiency that modern day practice has brought about is large. This increase has come about from the combination of two essentials: the improvement in furnace design, and the mechanical improvement in the stoker proper as a piece of operating apparatus.

Improvements in furnace form and mechanical improvements have come together; that is, as some change has been made in the mechanical construction tending toward the betterment of fuel feeding, air admission, or the like, some modification of furnace form has been found advisable to meet the new conditions of combustion. The two factors are, therefore, very closely related.

The features bringing about the possible added efficiency of the day might be summed up somewhat as follows:

(a) Truly Mechanical Features.

1. A continuous and automatic fuel feed obviates the necessity of frequent openings of any fire doors. In this way the great quantities of air admitted over the fire at every firing interval in hand fired practice are absent, and there is no deleterious effect on the boiler efficiency due to such air admission and no sudden cooling of the furnace. The result of maintaining a constant furnace temperature is obvious, both on the boiler efficiency and the life of the furnace brickwork.

The automatic feature of the feeding of the coal to the furnace affects the broad plant economy rather than the actual performance of the boiler and will be considered later.

2. The progressive movement of the fuel over the grates. The mechanical improvement here has in reality only to do with the actual movement of the fuel in different stages of its combustion, but closely related to this movement is the mechanical design of the apparatus which admits the proper amount of air during the progressive combustion, the combustion—assuming proper air admission—being taken care of by proper furnace form.

This feature of proper air admission is unquestionably one of the most important factors in the bringing about of high efficiencies, and primarily depends upon stoker rather than furnace design. The advantages of burning coal, or in fact any fuel, with the minimum amount of air, is too thoroughly under-

stood to need discussion here. When it is considered that with the modern stoker it is now possible, under test conditions, to reduce the ratio of air actually supplied to that theoretically required to 1.2 to 1, the greatly increased efficiencies possible are obvious. These figures, of course, represent test conditions, but numerous plants are operating with a ratio of 1.4 or 1.5 to 1 where previously ratios of 2 to 1 or 3 to 1 were common in hand fired plants.

The air admission in modern stokers of the underfeed forced blast type is often automatically controlled by the stoker speed, giving, theoretically, the proper amount of air for different combustion rates. While the proper action of such automatic air regulation must of necessity be checked from time to time, good results are secured in ordinary practice.

With properly designed natural draft stokers, the air is admitted in the right proportion to the different parts of the fuel bed, and the total amount of air supplied for different capacities is governed by varying the draft. Much has been done in recent years in developing automatic draft regulators for regulating the furnace draft, the air admission and combustion rates.

3. The quick and automatic removal of the ash and refuse, which for many years has been a distinctive feature of the chain grate stoker, has reached a stage of perfection in other stokers in line with the improvements in the mechanical features of the stokers. The ash removal, as now accomplished in the better class of stokers, is more or less continuous and practically does away with all cleaning intervals. Such intervals were formerly fairly frequent, often of considerable duration, and, regardless of the efficiency secured between cleaning intervals, the great amounts of air admitted during cleaning and the consequent cooling of the furnace and setting as a whole, could not but have an appreciable effect in lowering the efficiency in regular plant operation.

The purely mechanical features of modern stokers leading to high efficiencies may be summed up as the perfection of the automatic features which comprise the entire automatic feeding of the fuel, its automatic movement through a properly designed furnace, and the automatic and continuous discharge of ash and refuse.

(b) The Factor of Furnace Design.

While it is possible to be more or less specific in indicating the part mechanical construction has played in the bringing about of the modern high efficiencies, when it comes to a consideration of the part played by furnace design, only a most general statement is possible. This is due to the fact that equivalent results may be secured with entirely different combinations of boilers, stokers and fuels, the conditions surrounding each individual installation having necessarily to be considered separately.

The underlying principles of furnace form or design that have aided in bringing about the modern efficient furnace may be broadly summed up as follows: A form such that the volatile gases are driven from the coal before combustion proper takes place and such as to permit the air supply, properly admitted by reason of mechanical construction, to be so mingled with the volatile gases that the mixture is completely consumed before the boiler surfaces are encountered. Such a proper combustion of the volatile constituent of the coal almost automatically insures the proper combustion of the remaining combustible, assuming, of course, the proper mechanical air admission for different stages of combustion throughout the furnace. Further, such a proper combustion insures a high furnace temperature which, assuming the proper draft conditions and correctly designed gas passage areas from the furnace, is the ultimate indication of high furnace efficiency.

In the foregoing, the added efficiencies that have been brought about by mechanical improvements in stokers and improvements in the design of furnaces are the actual thermal efficiencies of the combined boiler and stoker units. In the sense of the broad plant efficiency—the cost per unit of power—there are a number of factors that have had a direct bearing. Some of these factors are the results of mechanical or furnace form improvements, and others are entirely apart from the combined unit as a piece of operating apparatus. These features may be enumerated as follows:

(1) The labor saving possible. An enormous saving has been accomplished in stoker fired plants by the intelligent use of properly designed coal and ash handling machinery. This saving is primarily effected by mechanical improvements in

apparatus apart from those of the stoker proper, for it is to be remembered that even if a stoker feeds coal to the furnace and removes ash from the furnace automatically, if the coal has to be fired by hand to the stoker hopper or the ash removed by hand from the ash-pit, there may be no saving of labor. The form of the ash-pit may result in a labor saving, in that ash may be carried to the ash handling apparatus by gravity. Much has been done recently in arranging the form of the soot collecting chambers throughout the boiler setting in such a manner that the accumulation of soot and dust may be readily removed by mechanical means, or with certain classes of coal, by gravity, and an appreciable labor saving is effected by this means.

(2) Low operating cost. This is a result of improvements in the mechanical design of the stoker. Enormous quantities of fuel are fed to furnaces today with a cost for the actual manipulation of the stokers that is practically negligible as compared with hand firing.

(3) Low maintenance cost. This is a result of both mechanical and furnace design improvement. In mechanical construction, the better stokers have today reached a stage where replacements are reduced to a minimum and this under the most severe conditions of service. The design of the modern furnace is such that the heat generated is properly distributed to the boiler and not concentrated to reduce the life of the stoker moving parts. Fire-brick have reached a stage in manufacture where even the heaviest duty does not require furnace brickwork replacements for considerable periods. And as a particularly important factor, engineers have come to realize the part that draft conditions play in the life of the furnace and the stoker. All of these items tend to lengthen the period of operation or decrease the number of shut-downs for replacement and repair.

(4) The human factor plays its part, in the better class of labor that is gradually being employed in the boiler room. This applies not only to the actual boiler operators but to the engineers supervising the boiler room operation. Of this latter class more will be given later.

(5) Smokeless, or rather, more nearly smokeless combustion resulting from stoker and furnace improvements may per-

haps be looked upon as an incidental result. Such improvements, with the end in view of increased efficiency, have naturally had a tendency to reduce smoke, and conversely the efforts toward smokeless combustion, frequently under compulsion, have unquestionably done much to improve furnace design, for the more nearly smokeless combustion is accomplished, assuming that the smokelessness is not the result of great quantities of excess air, the better such combustion will be.

Regardless of whether smokelessness is considered a cause or an effect, it has certainly had a bearing on the broad plant economy. With the absence of smoke and dust comes a lessening of wear and tear on machinery, an absence of damage to surrounding property, and a freedom from embarrassment from City Smoke Ordinance officials.

All large communities, and many smaller ones, are passing or have passed ordinances regulating the amount of smoke that may be emitted from a boiler stack. While such ordinances are uniformly praiseworthy in the object they seek, they are all alike lacking in that they specify no practical standard of comparison by which the density of smoke may be determined. The Bureau of Mines, Department of the Interior (Bulletin 49, 1912) offers a suggested form of smoke ordinance that is perhaps the most comprehensive of those to date. It should not be imagined, however, that the passage of a smoke ordinance is a solution of the smoke abatement problem. In considering the question, it must be remembered that the whole question of smokelessness is a comparative one. There is no arrangement of furnace and boiler that, under certain conditions of operation, will not emit smoke. And in a great measure, the degree of smokelessness is dependent upon the knowledge of the operating crew.

Another factor affecting the higher thermal efficiency now being secured, which is entirely apart from the boiler and furnace, is the use of steel boiler casing. This construction is coming more and more into use in the larger central stations.

It is rather difficult to state accurately the added efficiency due to the use of such a casing. The ordinarily accepted advantage of a boiler casing is the reduction of radiation losses. Where a steel casing is properly insulated, the saving in efficiency is made up not only of decreased radiation but also, as compared

with the ordinary brick setting which has been in use for some time, the loss due to air infiltration through the unavoidable cracks.

A steel casing alone, set over the boiler brick setting, while it would effectually prevent air leakage, would in no way reduce radiation losses, and the saving so effected would probably not warrant the cost of such an uninsulated casing. Where proper insulation is used between the brickwork and the steel casing, however, the saving unquestionably warrants the expense.

Considering both radiation and air leakage, a properly insulated steel casing will show a saving of from ¾ to 1 per cent. over the average new brick setting. Such a casing will remain equally effective over long periods, and its saving, as compared with a brick setting that has been in service, say, a year, would probably amount to 3 per cent. In modern power plant practice, because of the severity of service, brick settings deteriorate rapidly and the cost of keeping such settings tight is considerable. Since the properly constructed steel casing preserves its insulating qualities for long periods and prevents air leakage indefinitely, the cost of upkeep of the brick setting should be credited to the steel casing in the consideration of the broad plant economy. On such a basis, the modern tendency toward the use of this construction is readily understandable.

Consider now the tendency, particularly in this country, toward the increase in capacity demanded from a given heating surface. It is not many years ago that all boilers were rated, first, on 13 square feet, and then on 11½ square feet of heating surface per nominal horse power, and when a boiler developed its rated capacity, even on this basis, it was considered that all was being done that could be expected. Boiler manufacturers next rated their product on 10 square feet of heating surface per nominal horse power and in stationary boiler work this basis is used today. Such a rating is equivalent to an evaporation of 3.45 pounds of water from and at 212°F. per hour per square foot of surface. In view of the evaporation per square foot of heating surface that is being secured in daily practice in thousands of plants throughout the country, there is apparently cause for the widespread agitation against such an irrational method of rating the power of boilers.

The modern tendency toward demanding more capacity from boiler heating surface is clearly indicated by a comparison of the boiler horse power supplied for successive generating units in use in one of the largest and most modern plants in the United States. The Commonwealth Edison Co. of Chicago installed, in 1903, the first 5000 kilowatt turbine erected in this country. For this unit, which had a maximum rating of 7500 kilowatts, eight boilers were supplied, each containing approximately 5000 square feet of heating surface, or, on a 10 square foot basis, a total of 4000 boiler horse power. Later, a 12,000 kilowatt maximum unit was installed and for its operation eight identical boilers were supplied. Still later, a 14,000 kilowatt machine was installed and the boiler power supplied was again a duplicate of that furnished for the 7500 kilowatt set in 1903. In 1910, this Company installed two 20,000 kilowatt machines for each of which there were supplied ten 500 horse power boiler units, or 5000 nominal rated horse power. In 1913, two sets were installed with maximum outputs of 20,000 and 25,000 kilowatts respectively. For each of these two sets four boilers containing 12,200 square feet of heating surface each, or 4880 nominal rated horse power were supplied. In 1915, this Company installed a 30,000 kilowatt set for which there were supplied five 1220 horse power boiler units.

From these figures, it appears that where, in 1903, 4000 rated boiler horse power were considered necessary for a unit whose maximum output was 7500 kilowatts, in 1915, for a unit four times as large, but 50 per cent. more boiler horse power is deemed necessary. Of course there is a considerable difference in the efficiency of the two generating sets, but the difference in boiler horse power supplied is so widely varied as to furnish conclusive evidence of the tendency toward increased boiler capacities.

Since there have been no radical changes in the designs of the pressure parts of the boiler within recent years, the success in securing the modern high rating must be attributed almost entirely to improvements in the methods of feeding fuel to the furnace and in the design of this furnace.

The inherent ability of a given amount of heating surface to absorb heat has been present since the boilers have been con-

structed along the lines of modern design. The difficulty has been the supplying of sufficient heat to the heating surface. It has long been appreciated that the capacity of a given amount of heating surface, that is, its ability to absorb heat, was limited with certain restrictions, only by the amount of fuel that could be burned under such heating surface.

The amount of grate surface that can be placed under a given heating surface is limited by certain features of practicability of handling, of first cost, and of upkeep cost. With such limitations, capacity became a question of combustion rates. With the old methods of firing fuel and the limitation in size of combustion chambers, the maximum rates of combustion that could be secured were hardly comparable with what are today considered low rates. One has only to look over the boiler tests run "for capacity" of twenty years ago to appreciate this fact.

The possibility of the modern combustion rates has come only with a more thorough understanding of the relation of air supply to combustion. This contemplates not only a knowledge of the proper methods of feeding fuel to the furnace but a knowledge of introducing the air for combustion, the proper methods of handling the gases of combustion in the furnace and in introducing them into the heating surface in the most advantageous manner. The manner of passing these gases over the heating surface in such a way as to give the maximum heat absorption is properly one of boiler rather than of furnace design, and the only changes in recent years have been shown to be not so much in design of pressure parts as in minor details of baffling.

The high combustion rates necessary for the capacities carried in modern practice are made possible by the great improvements in the mechanical means of feeding fuel to the fire, the methods of introducing air for combustion, and the radical changes in the design of combustion chambers beneath the boiler, all of which factors have been discussed in the consideration of modern increased efficiencies.

The high rates of combustion made possible by stoker installations are attained without an appreciable loss in boiler and furnace efficiency, and, due to the proper relation of grate and furnace to the boiler heating surface, efficiencies are common in

modern practice at rates of evaporation of 7 pounds per square foot of heating surface per hour that were formerly not considered possible at rates of 3.5 pounds. The ability of the modern stoker to burn coal economically at high combustion rates necessitates a low percentage of unburned carbon in the ash. When stokers were first introduced, it was no unusual thing for the ash discharged to show at least 40 or 60 per cent. of unburned carbon. In power plant practice today many properly operated stokers are showing less than 20 to 30 per cent. unburned carbon in the ash at high rates of combustion, a figure which compares favorably with the best class of hand firing at combustion rates such as to give only low capacities from a boiler.

It should not be implied from the foregoing that the stoker fired furnace is the universal cure-all for boiler ills. There are numberless cases where the installation of a stoker is in no way warranted. If coal and ash handling machinery is not installed in connection with the stoker, the advantages resulting from the automatic feeding of the fuel to the furnace are largely lost. In small plants, as in temporary installations, the cost of coal and ash handling apparatus is not justifiable, and stokers are permissible, perhaps, only where the question of smoke is paramount.

Furthermore, there is no stoker that will satisfactorily handle all classes of coal and, in fact, there are some coals that can be burned with reasonable success in hand fired furnaces that cannot be handled by any stoker manufactured today. In making a selection of stokers, it is important that the type be chosen that has been shown, in actual practice, to give the best results with the particular class of coal to be burned. While stokers are largely automatic in their operation, it is to be remembered that they require more expert attention than do hand fired furnaces. Stoker first cost and upkeep cost are higher than with hand fired furnaces. The upkeep cost of the furnace brickwork, too, is greater, due to the more severe furnace conditions. So many factors enter into the problem that each individual set of conditions must be considered by itself, and the advantages due to increased efficiency and greater capacity without loss of efficiency of stoker firing over hand firing, must be carefully balanced against cost, operating expense, and the like, before it can be determined that one or the other method is preferable.

The references that have been made to capacity have been in connection with stoker fired coal furnaces. Higher capacities are being secured, too, in hand fired furnaces, but the cause here is almost entirely the improvement in furnace design, as the ability to shovel coal by hand has not increased appreciably. Hand fired capacities are limited by the ability of the fireman, draft and the like, and it is rarely that capacities of over 150 per cent. are secured for any but peaks of short duration.

While an endeavor has been made to separate the consideration of efficiency and capacity, it has been clearly indicated that the factors leading to present day overloads and modern increased efficiencies are practically the same.

The same improvements in boiler furnace practice, mechanical and of form, which have made possible both greater capacities and high efficiencies, have enabled the modern boiler to meet three constantly recurring conditions in plant operation with infinitely better results, from the standpoint of broad economy, than formerly.

First, the ability of a boiler to be placed on the line quickly, either from a condition of bank or from a cold boiler. Second, the ability of a boiler or boiler plant to handle widely varying and rapidly fluctuating loads without appreciable variation in efficiency. Third, the ability of a boiler to carry continuous high overloads without an excessive drop in efficiency.

The first condition, the ability of a boiler to be placed in operation quickly from a banked or a cold state, is of the utmost importance in auxiliary or standby steam plants and in plants where the method of operation is such as to cut in boilers from bank at peak load periods. The modern methods of fuel feed and the proper relation between furnace form and fuel have made it possible to bring boilers onto the line in an incredibly short time. What may be done along these lines may perhaps best be shown by an example.

In a standby plant equipped with 640 rated horse power boiler units, it is customary to carry the fires on bank, never letting the steam pressure fall to a point 10 pounds lower than the working pressure, the fires being held in such condition that they may be broken up at a moment's notice. Under such conditions it was shown that a boiler which had been on bank for

24 hours could deliver steam at the rate of 20,000 pounds per hour, or approximately its rated capacity, three minutes after the ash doors and damper were opened and fires broken up; and that three minutes later it was delivering steam at the rate of 50,000 pounds per hour, or 260 per cent. of its rated capacity. In this plant, the boilers, when called upon to take up the load, are capable of delivering their maximum capacity before the turbines are up to speed.

In this same plant, some tests were run in bringing up a cold boiler and cutting it into the line. With a temperature of water in the boiler of 150 degrees (there had been no fire in this boiler for 48 hours), the boiler was cut into the line at 172 pounds gauge pressure in 51 minutes and 20 seconds after the fires were started. In 5 minutes and 10 seconds after cutting in, the boiler was delivering steam at the rate of 35,000 pounds per hour, or 180 per cent. of its rated capacity.

Considering the difference in stationary and marine boiler design, these figures compare favorably with what is secured in marine practice. In this class of work, the record for getting up steam from a cold boiler quickly is held by one of the boilers of the U. S. S. "Cincinnati". From a temperature within the boiler of 72 degrees, steam was raised here to 215 pounds in 12 minutes and 40 seconds.

In a plant burning oil fuel, a similar test was run on a boiler of 640 nominal rated horse power. The temperature of the water in this boiler, which had stood for 50 hours with all doors and dampers open to cool the setting, was 122 degrees. The boiler was cut into the line at 175 pounds pressure 26 minutes and 30 seconds after lighting the oil fires, and 6 minutes after cutting in was delivering steam at the rate of 50,000 pounds per hour, or 260 per cent. of its nominal rating.

The second condition, namely, the ability of a boiler plant to handle widely and quickly fluctuating loads is of the greatest importance in plants where the method of operation is such that load changes are taken care of by a variation in the capacity of the boilers already operating on the line.

The mechanical construction of the modern stoker is such that the rate of fuel fed can be altered almost instantaneously and the draft conditions altered to meet rapid changes in the

required combustion rates. The furnace form is such that the products of combustion are handled efficiently, almost regardless of the changes in their volume. The result is not only the ability of the plant to handle such loads, but to handle them without material losses in thermal efficiencies of individual units. Widely varying loads are carried today in ordinary plant operation with over-all efficiencies higher than those formerly secured for constant loads and test conditions.

Fig. 4 shows two day load curves at the plant of the Edison Electric Illuminating Co. of Boston. While perhaps these loads are unusual, they are representative of the fluctuations that are encountered in hundreds of plants throughout the country under certain conditions. Considering that of March 23rd, 1914: At 1 o'clock the boilers on the line (23 in number) were operating at about 110 per cent. of their rated capacity; at 3:30, at 155 per cent.; at 4:15, the peak was reached, or 243 per cent. of the rated capacity of the boilers. The load had decreased again at 5 o'clock to 155 per cent. of the boilers' rated capacity. It is of particular interest to note that during this peak no additional boilers were cut into the line and that the steam pressure at no time fell more than 10 pounds below the maximum.

The third condition, namely, the ability of the modern boiler and furnace to operate over considerable periods at high capacities, has already been discussed in a general manner, in considering modern plant tendencies.

When it comes to a specific discussion of high capacities, the question arises as to what may be considered a high capacity in present day practice, and it is this question that is one of the most difficult for engineers and boiler manufacturers to answer, especially to the average boiler user—the man operating plants of 1000 horse power or less.

There are plants throughout the country in which boilers are developing, during periods of peak loads, capacities of 300 per cent. of the rated load and above. The central station operator fully appreciates that such high overloads are desirable only over short periods, and would not contemplate such capacities for average or continuous operation. The small plant operator, on the other hand, seeing reports of these capacities in the semi-technical engineering press, because he does not distinguish be-

tween peak load capacities and average operating capacities, sees no reason why his boilers should not be operated at similar capacities.

It is questionable whether there are twenty plants throughout the country operating continuously, day in and day out, at

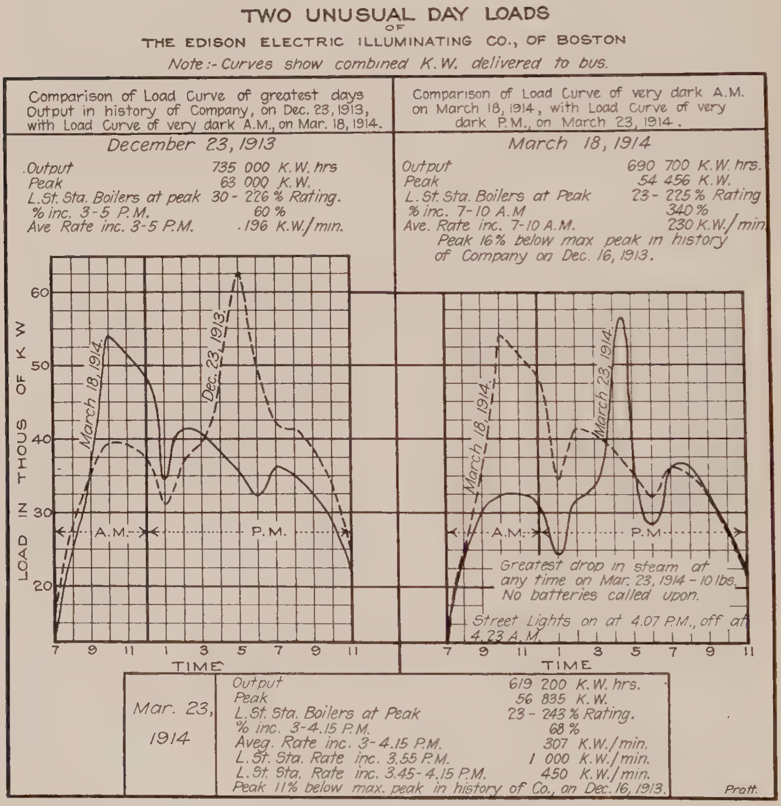


Fig. 4.

capacities of 175 per cent. of the rated load or over. The figures published from time to time that show capacities of over 250 or 300 per cent. of the rated load are ordinarily figures secured on tests that have been run to show what boilers are capable of doing during peak loads, and not with the idea that these capacities are the continuous operating capacities of the boilers. The interest-

ing fact in these high capacity figures, apart from an indication of what the modern boiler can do, is that during peaks the efficiency remains relatively high and this at ratings from 200 to 300 per cent.

The greater number of high capacity tests have been run, as stated, largely for the determination of the capacity, and are ordinarily of such a length that the efficiencies shown by the tests may be questioned. There are, however, a number of tests at high capacities on record which are of sufficient length, and which have been run with a sufficient degree of accuracy, to bear out the above statements.

In two tests of the Detroit Edison Co.'s large boiler units, to which reference has already been made, of 24 and 26½ hours' duration, capacities of 196 and 211 per cent. of the boiler's rating were secured, with efficiencies of 75.6 and 75.8 respectively. It is interesting to note that in these tests, eighteen in number, over a range of from 80 to 211 per cent. of normal capacity, the variation in efficiency was all within a range of 5.6 per cent.

In two 10-hour tests of a 500 horse power unit, capacities of 253 and 316 per cent. were secured, with efficiencies of 69.4 and 67.6 per cent. respectively.

In a test of 5 hours' duration of a 500 horse power unit, a capacity of 300 per cent. was obtained, with an efficiency of 69.7 per cent.

Fig. 5 is interesting to show the ability of the modern boiler to carry high overloads. From this chart, between 8 A. M. and 11:30 the boiler is developing 3240 horse power, or 137 per cent. of its rated capacity. From 12 o'clock until 1 o'clock, the load increases to 5076 horse power, or 214 per cent. of the boiler's rated capacity. Between 1 o'clock and 4:30, the boiler is delivering an average of 5300 horse power, or 224 per cent. of its rated capacity, and during this period the efficiency was over 70 per cent.

In view of the possible overloads, as indicated by the above figures, the question arises as to the capacity at which a boiler plant should be run to show the highest operating efficiency. The governing factors here are so numerous that only the very most general statement may be made. The ability of individual units to be operated at very high capacities over periods of peak load

has been shown, and in speaking of practicable operating capacities, it is intended to consider the average load advisable.

Primarily, the controlling factor in a boiler plant, that is, the number of boiler units that must be installed, regardless of

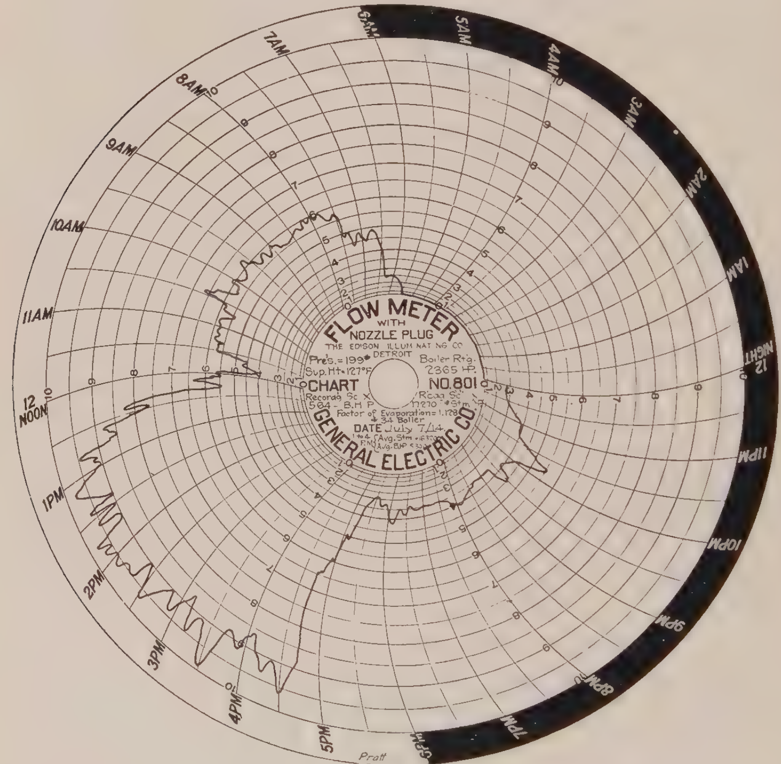


Fig. 5.

the nature of the load, is the ability to carry the maximum load that may be thrown on the plant under any conditions.

The concensus of engineering opinion respecting the best operating capacities for boilers is somewhat as follows:

For a constant 24-hour load, the operating capacity, to give the highest over-all plant economy, is between 125 and 150 per cent. of the boiler's normal rating.

For the more or less constant 10- or 12-hour a day load, where the boilers are placed on bank at night, the point of maxi-

mum economy will be somewhat higher, probably between 150 and 175 per cent. of the boiler's rated capacity.

The third class of load is the variable 24-hour load found in central station work. Here, even more than with the other classes of loads, the statement as to the economical point of operation must be general, due to the variation in handling, with differences in fuel, labor, type of stoker, flexibility of operation of the boiler and furnace, and other factors.

Modern methods of handling loads of this description, to give the best operating results under different conditions of installation, are as follows:

(1) The load on the plant at any time is carried by the minimum number of boilers that will supply the power necessary, operating these boilers at capacities of 150 to 200 per cent. of their normal rating. There is, perhaps, an increasing tendency toward the higher figure. Such boilers as are in service are operated continuously at these capacities, the variation in load being cared for by varying the number of boilers on the line, starting up boilers from a banked condition during peak load periods and banking them after such periods. This is, perhaps, at present the most general method of central station operation.

(2) The variation in the load on the plant is handled by varying the capacities at which a given number of boilers are run. At low plant loads the boilers are operated somewhat below their normal rating, and during peak loads, at their maximum capacity. The ability of the modern boiler to operate over wide ranges of capacities without appreciable loss in efficiency has made such a method practicable.

(3) The third method of handling the modern central station load is, perhaps, only practicable in large stations or groups of inter-connected stations. Under this method, the plant is divided into two parts. What may be considered the constant load of the system is carried by one portion of the plant, operating at its point of maximum economy. Due to the possibility of very high over-all efficiencies at high boiler capacities where the load is constant, where the grate and combustion chamber are designed for a point of maximum economy at such capacities, and where there are installed economizers and such apparatus as will tend to increase the efficiency, the capacity at which

this portion of the plant is today operated will be considerably above the 150 per cent. given as the point of highest economy for the steady 24-hour load for boilers without economizers.

The variable portion of the load on a plant so operated is carried by the second division of the plant under either of the methods of operation just given.

It may not be out of place to again point out the very general nature of these statements as to the economical load for any plant, and to emphasize the fact that each individual set of plant operating conditions must be considered by itself.

Apart from the question of furnace and stoker design, there are three factors, to which reference should be made, that have an important bearing on the determination of the point of maximum continuous overload.

The first of these factors is feed water. Engineering opinion is coming more and more to recognize that where high boiler overloads are either expected or required, it is essential that the feed water be particularly free from scale forming ingredients and matter which might tend to cause foaming or priming. While the design of the boiler plays a part here, in that certain boilers at high capacities will handle, without difficulties, waters that cannot be handled with other boilers, the water itself is the more important factor in any boiler.

The second factor is furnace brickwork. With the increased combustion rates of modern practice and the higher furnace temperatures of the present day furnace, the conditions which the brickwork of the furnace is called upon to withstand are much more severe than in former practice. Fortunately, progress in the art of brick manufacture has to a certain extent accompanied the movement toward higher capacities, and firebrick as manufactured today, when properly installed, are able to withstand, over considerable periods and under practically all conditions of service, temperatures and variations in temperatures that some fifteen years ago were not practicable from the standpoint of furnace upkeep cost.

The third factor is that of draft,—draft not as affecting combustion rates, but in its connection with the life of the brickwork setting, particularly the furnace brickwork.

Many of the successful stokers of today are utilizing a

forced draft for their operation. At one time it was assumed that this class of stoker did away with the necessity of a stack, except for carrying off the gases of combustion. As combustion rates increased, however, and it was necessary to supply more and more blast, it became evident that, from the standpoint of protection to furnace brickwork, a draft suction was necessary as well as a blast. In view of the enormous heat now developed in stoker fired furnaces and the great weight of the gas passing over the boiler heating surfaces, it is now generally accepted that some means must be provided, whether by natural or induced draft, to remove these gases from the furnace promptly in order to prevent a "soaking up" action of the heat by the furnace brickwork. To assure such removal, the means provided should be such as to give a draft suction throughout all parts of the setting under any conditions of service.

In the foregoing discussion of efficiency and capacity and the factors bringing about the modern increases in both, the fuel considered has been in all cases coal. Greater capacities and higher efficiencies, however, are by no means limited to this class of fuel. Strides in furnace design for all classes have been as great as for coal, and furnace design today may be considered as much a specialization as any of the highly specialized branches of engineering.

Of the fuels aside from coal now in use, oil is by far the most common, and, because of the enormous increase in the available supply, in all probability it will be even more generally used in the near future.

In general, the factors that have brought about modern increased efficiencies and capacities with oil fuel are the same as have been discussed in connection with coal. The design of oil furnaces and oil burners has possibly reached a state of perfection in advance even of coal fired design.

The methods of burning all classes of oil fuel successfully are similar. The development of the modern efficient oil burning furnace, therefore, has been helped by the fact that it has been necessary to experiment with but one set of conditions, as compared with the innumerable conditions encountered in developing successful furnaces for the countless classes of coals found in different regions.

With oil fuel, assuming a properly designed boiler, the furnace form and the methods employed for introducing air for combustion are of the utmost importance. Experience has shown that the furnace design with which the best results are secured is one in which the oil is introduced into the furnace in the direction in which it increases in height. This increase in furnace volume in the direction of the flame insures free expansion, a thorough mixture of the oil with the air, and the consequent complete combustion of the gases before the boiler heating surfaces are encountered. Air admission to the modern efficient oil burning furnace is such that under operating conditions it is possible to run with a ratio of actual air supplied to that theoretically required of 1.25 to 1. Due to the improvements in furnaces and burners, efficiencies and capacities are being secured in every day plant practice that would have been looked upon as impossible at the time oil was first used.

The over-all oil fired plant economy has been increased greatly by improvements in the methods of handling, pumping and heating oil and in storage methods.

The tests run at Redondo a number of years ago in one of the Pacific Light & Power Co.'s plants probably still hold the record of high efficiency, and that this efficiency was over 83 per cent. gross clearly indicates what may be accomplished with this fuel. Because of the possible close regulation with oil fired boilers, test conditions can be more nearly approached in ordinary operation than is the case with coal fuel, and many plants are operating continuously at a gross efficiency above 76 per cent.

In stationary boiler practice, steam atomizing burners are in general use, and much has been done within the last few years to reduce the steam consumption of the apparatus. At Redondo, in the tests to which reference has been made, the steam used by the burners was approximately 2 per cent. of the total generated, giving for a gross efficiency of 83 per cent., a net efficiency of 81 per cent. Refinement in burner design has made possible today a steam consumption by the burners of as low as 1 per cent. The Redondo efficiencies represent about the maximum possible with oil fuel, and it is, at efficiencies as high as this, difficult to secure any additional increase. When the 1

per cent. increase in net efficiency obtained by a reduction in the steam consumption of the burners is compared with the very small increases that further improvement in furnace design can bring about, its importance may be realized.

Oil fired stationary boilers are being operated at overloads nearly as high as are coal fired boilers and with a falling off in efficiency probably not as great. The record for capacity with oil firing was secured on a marine boiler where an evaporation from and at 212 degrees, per square foot of heating surface, of 18.7 pounds was secured. On the ordinary basis of rating stationary boilers, this would be at the rate of 540 per cent. of rating. This capacity was secured with an efficiency of 78 per cent. These figures represent capacities considerably higher than have been obtained with stationary boilers.

Another class of fuel used in considerable quantities in this country, particularly in lumber mills, is wood refuse. With this fuel, the results sought until recently have been of capacity rather than of efficiency. From this standpoint, the fact that boilers are being operated at over 200 per cent. of their rating, and that with wood refuse containing over 40 per cent. of moisture, indicates how satisfactory the improvements in wood burning furnace design have been. In a number of mills much of the refuse hitherto burned has a commercial value due to certain by-products that may be secured, and where attention has been given to the efficiency aspect, as well as to that of capacity, the fact that the volume of refuse saved for outside uses has increased appreciably shows a distinct advance in this class of special furnace design.

The burning of green bagasse (sugar mill refuse) by present methods is another indication of the high state of development in special furnaces. On sugar plantations today, bagasse, instead of being an auxiliary fuel, is burned so efficiently that in many instances no other fuel but bagasse is required to operate the entire mill. Formerly, considerable quantities of coal or wood fuel were used as auxiliary fuel. Today, practically no auxiliary fuel is required, and this in spite of the fact that bagasse as delivered to the boilers is of much poorer quality for steam generating purposes than was the case some ten years ago.

Of the gaseous fuels used today, probably the most common is blast furnace gas. Here, as with wood refuse, capacity rather than economy was the object until recent years. Capacities of 175 to 200 per cent. are being developed in numerous steel plants with this fuel. In recent years, when attention has been given to economy, the efficiencies, as judged by exit gas temperatures, are in line with those secured with other fuels.

The statement was made at the beginning of this article that boiler design had changed not at all except in minor details. Possibly an exception to this statement should have been made for one class of boiler work, namely, the utilization of waste heat.

For years it was considered impracticable to make use of waste gases for the generation of steam where the temperature was below 1800° F. No attempt was made to re-gain the heat in gases of lower temperatures than this, and when boilers were installed for higher temperature gases, the primary object was to re-gain only such heat as was possible without interfering with the operation of the primary furnace. As draft was usually the main object, such boiler heating surfaces as were used were usually installed without baffles of any description, resulting in but a slight reduction in gas temperatures through the waste heat boilers and low capacities.

Within the last two years, there has been a considerable revision of ideas in the utilization of waste heat. The basis of design of the best waste heat boilers is the giving of the gases a high velocity over the boiler heating surfaces. The means of accomplishing this have been changes in the methods of design of gas passage areas rather than in the design of the boiler pressure parts. The higher gas velocities have, of course, resulted in additional frictional resistance or draft loss through the boiler, and in most instances this loss has increased to a point that necessitates the installation of an induced draft fan. The added capacity obtainable, however, has in every case very much more than offset the power required for such a fan.

Perhaps the most important feature of the change in attitude toward waste heat utilization is the present practicability of using gases of low temperatures. A few examples of what is actually being accomplished will best serve to illustrate this

fact. The lowest temperature gases with which a waste heat boiler installation has as yet been found practicable are probably those from the modern open hearth steel furnace. These temperatures run from 950° F. to 1400° and average approximately 1150°.

From a boiler containing 3600 square feet of heating surface with an entering gas temperature of 1153 degrees, 200 boiler horse power has been secured as an average for a week's run. This represents approximately 60 per cent. of the boiler's rated capacity. The open hearth furnace to which this boiler was attached is rated at 35 tons. From a second boiler installed in connection with a 75 ton open hearth furnace, with an entering temperature of 1360 degrees, 426 boiler horse power was obtained from 5230 square feet of heating surface in a test of 159 hours.

When it is considered that these gases have hitherto been discharged to the atmosphere, the saving in plant operation is obvious. The steel companies ordinarily value a boiler horse at $40 a year, and the return on the investment represented in the complete boiler, fan and connecting flue installation has proven to be between 60 and 70 per cent. The net saving in manufacturing cost is in the neighborhood of 20 cents per ton of steel produced.

Aside from the utilization of low temperature waste gases, great progress has been made, using the same basis of high gas velocity, in the use of waste heat having temperatures that approach those found in coal fired practice. An example of this class of work is found in beehive coke oven plants where the temperature of the gas runs from 2000 to 2300° F.

A boiler containing 10,000 square feet of heating surface, installed in connection with several batteries of beehive coke ovens, developed in an 8-hour test 1960 horsepower, or 196 per cent of its normal rated capacity. This capacity, of course, is a function of the volume of gas passing as well as of the velocity. The interesting feature of this result is that, with an entering gas temperature of 2158 degrees, the exit temperature was 477 degrees, interesting either when compared with coal fired practice for such overloads or for former practice with this class of waste gas. An installation made some ten years ago,

with beehive coke ovens, of approximately the same size and number, showed an exit gas temperature of 800 degrees. For the same volume of gas passing through the boiler as was utilized in developing the 1960 horse power, the same entering temperature, and an exit temperature of 800 degrees as against 477 degrees, the horse power developed would be 1577 as against 1956, or an increase, for the modern waste heat boiler in this particular class of work, of 24 per cent.

Successful installations of waste heat boilers have been made within the last two years with open hearth steel furnaces, billet heating furnaces, soaking pits, cement kilns, copper matte furnaces, gas benches and beehive coke ovens, and the return on the investment in every instance has been many times higher than that necessary to warrant the expense of installation.

Unquestionably, there is no one factor that has had as beneficial an effect in the securing of modern day boiler room results as the intelligent supervision of this portion of the steam plant, and nowhere has the "Efficiency Engineer" had such a chance to show improved performance. This supervision has come with the full realization of the wide difference existing in the results that were formerly secured in every day practice and those theoretically possible.

For this supervision, a full knowledge is necessary, not only of what a plant can do under the best operating conditions, but also a knowledge of what a plant will do under any and all of the conditions that may arise. The former knowledge is secured by a systematic testing; the latter by continuous records so arranged that the results may be directly compared for any period or any set of conditions.

The continuous records serve as a check on plant losses, and as the size of a plant increases such a check becomes a necessity. In a large plant, a saving of but a fraction of 1 per cent. in the fuel bill represents an amount running into thousands of dollars annually, while the expense of supervision is relatively small. The methods of supervision in a large plant are naturally elaborate and complete. In the smaller plant, the same methods are followed on a more moderate scale with a corresponding saving in fuel and without an appreciable increase in plant organization or expense.

Improvements in modern recording apparatus have led to reliability and accuracy, and are of great service in attaining proper operating results. Records of water evaporated and the fuel consumption are of primary importance. Other records of temperature, gas analyses, draft and the like, serve as a check on the fuel consumption. They permit an intelligent study of the distribution of losses and afford a means of remedying such losses where improvement is possible.

The boilers of the modern power plant are almost universally equipped with integral superheaters. Superheaters as now offered have been in common use in stationary boilers for some twenty years and during that time, as in the case of the modern boiler, there have been no radical changes in design. The superheaters introduced during the period 1895-1900 do not, however, represent the first use of superheated steam, and the modern superheater is essentially different from the apparatus first used for the purpose. In this connection, a word of superheater history is of interest.

Following Hirn's experiments of 1857 and Isherwood's in 1862-1864, there was a marked interest on the part of engineers in the use of superheated steam. By the late sixties, practically all marine boilers were equipped with superheaters, and while in stationary practice their use was more limited, numerous installations were made. The designs were many but all were alike in location, namely, in the uptake of a boiler. During this period, all boilers were operated under working pressures of less than 50 pounds, and 100 degrees of superheat with such pressures represented ultimate temperatures that could in no way be considered high.

The introduction of compound engines and the use of high pressure steam in the late sixties and early seventies combined to force the superheater temporarily out of the field. Such engines and high pressure steam showed an increase in efficiency over simple engines and the low pressure steam that had been in vogue, considerably greater than that obtained by simply superheating the low pressure steam. With the increased temperature due to higher pressures, it was found where attempts were made to superheat the steam to as great a degree as formerly, that difficulties were encountered in lu-

brication, and where superheat was used it was necessary to reduce the amount to a point where the gain secured did not warrant the expense of an installation.

How completely the use of superheaters was abandoned during this period is shown by a quotation from Seaton's "A Manual of Marine Engineering" (1883), appearing in editions as late as 1890: "The use of superheated steam has been discontinued since the pressure has gone beyond 60 pounds per square inch, partly in consequence of the increase in temperature beyond that due to the pressure being prejudicial to the good working of certain parts, partly also due to the danger and inconvenience of the superheater itself, and not a little to the action taken by the Board of Trade (British) with respect to it". In view of the present day knowledge of the properties of superheated steam, the Board of Trade's attitude referred to is of interest. This body took a strong stand against the installation of superheaters on the ground that the steam at high temperatures might break into its constituent elements with results that would be dangerous.

During this period, while the general interest in the use of superheated steam was apparently lost, certain engineers, prominent among whom were Hirn, Schwoerer, Schröter and Wilhelm Schmidt, continued to investigate and experiment. In 1895 Professor Schröter conducted a series of tests of a boiler and engine especially designed and built for use with superheated steam by Dr. Schmidt. The published results of these tests, showing as they did efficiencies which at the time were remarkable, re-aroused interest in the use of superheated steam and a number of Schmidt engines and superheaters were installed. This interest spread, particularly in Europe, and numerous designs of superheaters were placed upon the market within a few years after Schmidt's experiments. The first superheaters in this country were commercially marketed in 1898. From that time, their use has increased enormously, until, as stated, the boiler of today is almost universally equipped with an integral superheater.

The operation of all integral superheaters as offered today is alike, and different superheaters differ in constructional details rather than in essentials of design.

Experience has shown that for efficient operation, the modern superheater must meet certain requirements that may be summed up as follows:

Superheaters must be located in the direct path of the gases as they sweep over the boiler heating surface; that is, the gases utilized for the generation of steam must also be utilized to superheat that steam.

The location must be such that the full superheating surface is presented for contact with the gases, but the arrangement of surface must cause no undue amount of frictional resistance to the gases in their passage.

The surface should offer the least opportunity for the adhesion of soot and dust.

All parts of the superheater should be readily accessible for inspection and repair and the design should be such as to allow freedom of expansion without affecting the boiler proper or the setting.

All superheaters should be equipped with safety valves set somewhat lower than the boiler valves. This is necessary in order to insure a flow of steam through the superheaters when the load is suddenly taken from the boiler.

Practically all of the modern superheaters meet these requirements to a greater or less degree. In performing their function they interfere in no way with the operation of the boiler and their upkeep cost is negligible. The efficiency of a boiler equipped with an integral superheater is, without question, greater than the efficiency of a boiler in which no superheater is installed, but the added efficiency due to the superheater is difficult to determine.

For some years after the re-introduction of the use of superheated steam, there was a tendency on the part of steam users to demand degrees of superheat as high as could be obtained from integral superheaters. The use of such high temperatures led to a number of operating difficulties and particularly to trouble with the cast iron fittings in general use. These difficulties led to a decided reduction in the amount of superheat desired, and over the period of 1905-1912 the average degree of superheat, throughout this country at least, was probably considerably below 150 degrees. Operating difficul-

ties, however, were gradually overcome, turbines largely replaced reciprocating engines, and engineering opinion came to an agreement that steel fittings should replace cast iron fittings for superheated steam practice. Under the improved modern plant conditions, there seems to be, within the past two years, a strong tendency on the part of engineers toward the use of degrees of superheat considerably in excess of 150 degrees.

The use of superheated steam belongs rather to a discussion of prime movers than of boilers and is doubtless fully discussed in another paper.

Practically all of the foregoing has dealt with what may be considered the practical side of boiler practice. In closing, it may not be out of place to refer briefly to one phase of the theoretical side, namely, that of heat transfer in steam boilers.

Within the last few years, a number of papers have been presented on the subject of heat transmission from a hot gas to a metallic surface. A consideration of the three that have been, up to the present time, accepted as the most authoritative is of interest in indicating what has been done toward establishing the laws of heat transmission as affecting boiler design.

In 1909, Dr. Wilhelm Nusselt presented a paper on "Heat Transmission in Tubes" in the "Zeitschrift des Vereines Deutscher Ingenieur". This paper is apparently the first effort to investigate the subject in a thoroughly scientific manner. It is extremely interesting in that it presents the subject in an entirely new aspect and gives a formula for the calculation of heat transfer rates in tubes which is applicable to any fluid, liquid or gaseous.

The experiments upon which Dr. Nusselt's conclusions are based were conducted with an apparatus in which air and gas were heated in passing through a steam jacketed brass tube of 0.85″ internal diameter. The mean temperature of the gas was taken at two points about 20″ apart and at some distance from the entrance to the tube. Due to the method of determining gas temperatures there is reason to question whether the actual mean temperature was obtained.

From the observed data, the heat transfer rate was calculated, using the ordinary logarithmic formula corrected for the difference in temperature between the inside and outside sur-

face of the tube. Air was used at different pressures to determine the effect of density. The formula was checked by experiments with carbonic acid and illuminating gas. In working up the results, Dr. Nusselt also used the experimental data obtained by Knoblauch and Jakob in determining the specific heat of superheated steam, and thus further checked the formula.

The mean temperature of the heated gas in these experiments appears to be in the neighborhood of 35° C. (95° F.), while the steam in the jackets was at atmospheric pressure. Dr. Nusselt's results, therefore, must be understood as applying to heat transfer rates at comparatively low temperatures and with small temperature differences.

The accuracy of Dr. Nusselt's results from the data he gives is apparently good, but due to the low temperatures, the small temperature differences, and the small diameter of the tube used, they are not particularly valuable in assisting practical boiler design.

The second of the papers to which reference has been made was presented in 1909 before the "Institute of Mechanical Engineers" by Mr. H. P. Jordan under the title "On the Rate of Heat Transmission Between Fluids and Metal Surfaces".

Mr. Jordan's apparatus consisted of a cast iron casing approximately 40″ long, into which were fitted copper tubes. Three sets of experiments were made, using copper tubes of 2″, 1¼″ and ½″ internal diameter. Hot air was drawn by suction through the copper tubes. Water was forced through the annular jacket between the casing and the internal tube in an opposite direction to that of the airflow.

At the beginning and end of the water jacket the area of gas passage was reduced from the full area of the casing to that of the individual copper tube with which the experiment was being made. Entering and exit gas temperatures were measured by thermometers, the bulbs of which were approximately ¾″ and 1½″ respectively from the beginning and end of the water jacket. It is hardly possible that Jordan actually measured the true mean temperature of the gas as it existed in the tube, particularly at the inlet end.

There is further reason to question the inlet and outlet

temperatures due to the proximity of the thermometer bulbs to the surface of the water jacket.

Any inaccuracies of these temperature readings result in an incorrect mean gas temperature. Since this mean temperature is the basis of all calculation, it is obvious that some doubt must be cast on the results as a whole.

Jordan's experiments covered a range of gas flow from 5000 to 72,000 pounds per hour per square foot of gas passage area. There were but one or two cases where the rate of gas flow was as low as this 5000 pounds, and practically all of his results were at rates over 10,000 pounds per hour. In ordinary boiler practice, the maximum flow found is not in excess of 3500 pounds per hour, while even in waste heat work of today, where the highest velocities are encountered, this rate rarely exceeds 4500 pounds. Jordan's experiments, therefore, are at rates of flow that are not in any way comparable with boiler practice. Further, the diameter of the smallest tube used is such as to preclude the use of any of the results in that series of experiments.

The highest temperature difference between the air and the metal in Jordan's experiments is approximately 400° F., which, though it is considerably below that found in ordinary boiler work, is about the minimum difference found in waste heat work.

Jordan's results are expressed in the formula:

$$R = A + B\frac{W}{a}$$

where

$R =$ the heat transfer rate in B.t.u. per square foot per second per degree difference,

$A =$ a constant,

$B =$ a function of the dimension of air passage and mean temperatures of gas and metal,

$\frac{W}{a} =$ the weight of mass flow per unit of cross sectional area of channel.

The constant, A, as determined by Jordan, is 0.0015 B.t.u.'s per second per degree difference in temperature, or

$$0.0015 \times 36{,}000 = 5.4 \text{ B.t.u. per hour.}$$

Thus, on the basis of Jordan's value of the constant A, the minimum heat transfer rate, at no gas flow, is some 45 per cent. higher than is actually secured with a properly designed boiler at its normal rated capacity.

Jordan assumed the specific heat of air as a constant, which leads to other errors, for in boiler practice the specific heat of the gases varies from 0.24 to 0.30.

In 1912, the Department of the Interior, Bureau of Mines, United States Government, issued a bulletin (No. 16) by Henry Kreisinger and Walter T. Ray on the "Transmission of Heat in Steam Boilers".

The apparatus of these experimenters consisted of four small boilers all of the tubular type, with a shell of 4″ wrought iron pipe, 8¼″ long in three of the boilers and 16⅛″ long in the fourth. There were ten tubes in each boiler, of diameters from 0.175″ in the first boiler to 0.2928″ in the fourth. Air heated by an electric furnace was drawn by suction through the tubes of the boiler. The steam generated was condensed and weighed.

The diameters of the tubes used in these experiments are so much smaller than those found in boiler practice that Kreisinger and Ray's results, regardless of other factors, are of no value for application in the design of boilers.

Aside from this fact, there are a number of features in these experiments that would tend to cause the results to be questioned.

The weights of air per square foot of cross sectional area varied from 2220 pounds per hour to 24,900 per hour. While the lowest figure is comparable with what is found in boiler practice, although the diameter of the tubes was radically different, almost the entire range of experiments is at a rate of gas flow greatly in excess of anything encountered in either direct fired or waste heat work.

Kreisinger and Ray made no attempt to determine the moisture content of the steam generated by their boilers. When it is considered that in their experiments rates of evaporation per square foot of heating surface per hour as high as 28.75 pounds were used, or, on the ordinary basis of stationary boiler rating, 833 per cent. of normal capacity, it is obvious that there must have been considerable priming.

In these experiments, three thermometers were used to measure both inlet and outlet gas temperatures, and the fact that some of the readings of the same air temperatures differed as much as 100° F., would seem to cast some doubt on the accuracy of the temperature measurements.

No attempt was made to correct for the variation of specific heat of air at different temperatures, a fact which of necessity would lead to further error.

There has just been completed, under the direction of the Engineering Department of the Babcock & Wilcox Co., an extensive and remarkably comprehensive set of experiments on "Heat Transfer Rates". While the results of these experiments are not at this time in the form for final publication, the data, however, have been worked up to an extent that makes it possible to authoritatively state some of the laws of heat transmission as they apply to boiler design.

The apparatus used in these experiments consisted of a 2-inch internal diameter copper pipe, surrounded by 20 individual water jackets each 1 foot long. The gases were drawn from an illuminating gas furnace in which temperatures above 2600 degrees could be obtained.

The range of gas flow rate covered was from 4000 to 14,000 pounds of gas per hour per square foot of cross sectional area of passage. The difference in temperature between the gas and metal surface was from 400 to 2000° F. The temperature of the metal surface varied from 145 to 215° F., the average wall temperature being 180 degrees. The variation in specific heat of the gases was taken into account, the latest data on gases being used for these calculations.

The flue gases, after leaving the experimental tube, were made to pass through a cooler, where the gases were cooled in a 2-inch coil 26 feet long surrounded by water. The gases leaving the coil were passed through a box where the dew point was determined. The dew point, together with the entering and exit temperatures of the gas and water through the cooler, and the flue gas analyses taken during tests, gave the most accurate method of determining gas weights.

Tests extending over some three months were made, getting the apparatus into shape for the taking of final data. Dur-

ing this time, the proper locations of the thermometers used for measuring gas temperatures entering and leaving the cooler, to give the mean temperature, were determined. Radiation tests were also conducted and proper correction made in all results. As an indication of the accuracy of the experiments as a whole, it may be stated that specially manufactured thermometers were used, with a scale range that would cover the temperatures to be measured, graduated to .1 of 1 degree, so that the approximation of .01 of 1 degree was possible, and in the plotting of results (see Fig. 6), over 80 tests were used in determining each line.

Fig. 6 gives in graphic form the results of these experiments. While the range of gas flow tested is beyond what is found in ordinary boiler practice, the fact that this range is limited from 4000 to 14,000 pounds per square foot of gas passage area per hour (as compared with Jordan's range of 5000 to 72,000 pounds), and that within this range as many as 80 points were used in determining the lines (as compared with 4 to 5 points used by Jordan over a range seven times as great), makes it obvious that the direction of these lines below the lower limits of the experiments, that is, the transfer rates for gas flow lower than 4000 pounds, are much more accurate than could be possible in the other experiments.

The rate of heat transfer may be expressed by the formula:

$$R = A + B\left(\frac{W}{a}\right)$$

where

R is the rate of heat transfer,
A is a constant,
B is a function of the temperature difference, and
$\frac{W}{a}$ is the rate of mass flow per unit area of channel.

The value of A as determined by these experiments is 2.20. The value of B varies with changes in the temperature difference from 0.000770 for a temperature difference of 400° F. to 0.001120 for a temperature difference of 2000° F. These values of B may be readily obtained from the chart for any rate of gas flow and any temperature difference.

It is interesting to note from Fig. 6 that while at high rates of gas flow the temperature difference has an important bearing on the heat transfer rate, at low weights of gas flow, such as are encountered in boiler practice, the effect of the temperature difference is relatively small.

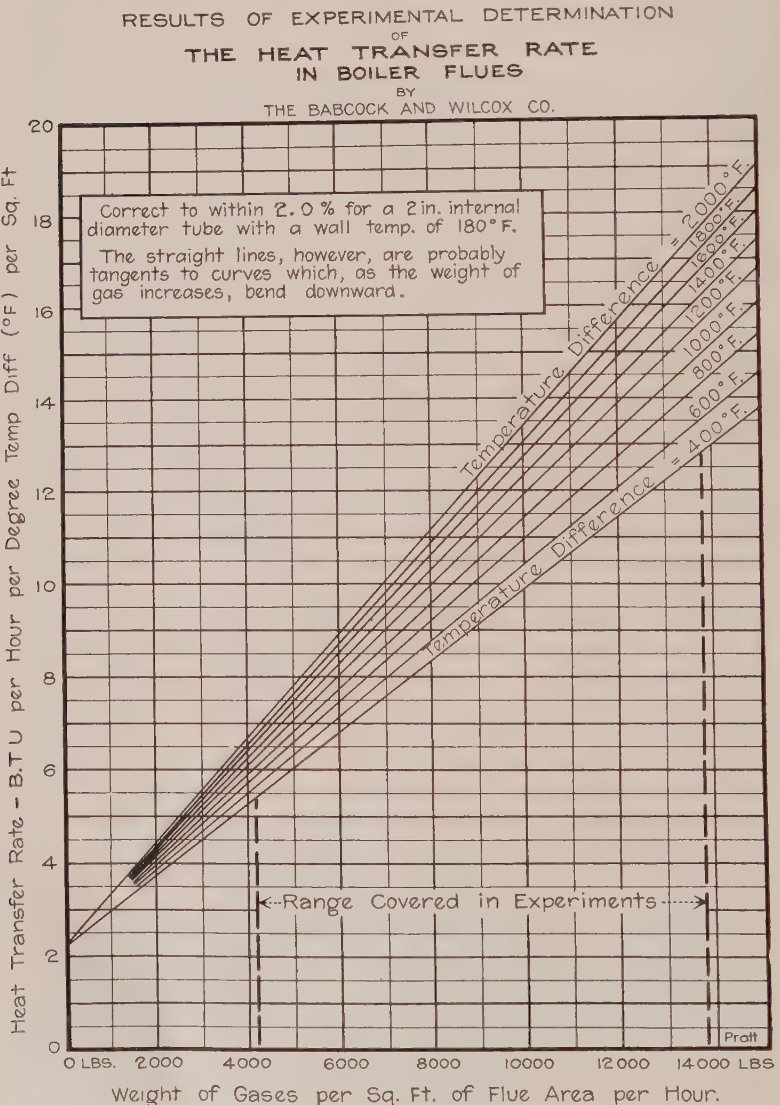


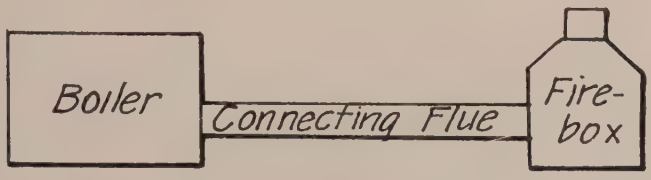
Fig. 6.

DISCUSSION

Mr. W. J. Davis, Jr.,* Mem. Am. Soc. M. E., in opening the discussion, regretted that the author had neglected the discussion of high pressures and high degrees of superheat. This was a most important problem, for, in the past, installations were designed for the following conditions: pressure, 300 lbs. per sq. in. with 250 degrees superheat and 29 inches vacuum; while present installations favored 600 lbs. per sq. in. pressure with 150 degrees superheat and 29 inches vacuum. This has been brought about by experiments. Dr. Stott says that pressures as high as 1000 lbs. per sq. in. are possible. Mr. Davis.

Since the limit, so far as turbine and condenser efficiency is concerned, has been reached (80 percent efficiency, Rankine cycle, and a vacuum of 29.5 inches mercury being possible) the only means left to raise the overall economy is to increase the boiler efficiency by increasing the pressure and working temperature of the steam.

Mr. R. Seshasayee,† Assoc. A. I. E. E., said that India was not very far developed so far as mechanical appliances were concerned. Due to the fact that they were forced to use light fuels, i. e., rice husks, they were faced with many difficulties in regard to boiler setting. The three types used are the Cornish, Lancashire and locomotive. The setting being as follows: Mr. Seshasayee.



The main difficulty is that the fusible plug does not provide adequate protection to the boiler plates. This is due to the fact that the firebox is separate from the boiler, as shown. We would like to have some information on how to overcome this condition, as India looks to America as the home of the inventor.

Mr. L. C. Bowes,‡ Junior Am. Soc. M. E., said that to place full confidence in boiler-room instruments was not justified by the facts. While a certain number were reliable, such as flow meters and fuel weighers, others, as CO_2 recorders, do not give reliable service as boasted by their manufacturers. This results from the fact that the samples are not good averages and consequently do not give correct operating conditions. The best way is to have regular periods for sampling from the flue. Mr. Bowes.

* Gen'l Electric Co., San Francisco, Calif.

† Trichinopoly, South India.

‡ Fuel Engr., Public Service Co. of No. Ill., Sta. 4, Blue Island, Ill.

Mr. Bowes. Smokeless combustion can be obtained on chain grates by carrying a short fire, but this results in a low efficiency.

Personal supervision can and has done more for economy than all the devices manufactured.

Mr. Weymouth. **Mr. C. R. Weymouth,**§ Mem. Am. Soc. M. E., stated that increasing the rate of combustion involves the efficiency of the furnace and the absorption efficiency of the boiler. Forcing the boiler with a coal fire increases its efficiency, but the contrary is true with oil. This is due to the different characteristics of coal and oil fires. It does not pay to force boilers with oil fuels, as the heat is localized and intense, and hard on the boiler. This is due to the fact that oil involves a surface combustion, while coal involves a volume combustion. A boiler with greater furnace volume will give higher overall efficiency at overload, but falls off at normal load.

In reply to the request of Prof. J. C. Scrugham for some discussion on the limits of modern superheating with reference particularly to the boiler and superheater, Mr. Weymouth answered that there were two kinds of superheaters, the externally heated and the self-contained. The limit of the externally fired type is the temperature of the flame, or that temperature which the metal will stand; while about 200 degrees limits the latter.

Mr. Hunter. **Mr. John Hunter,*** Mem. Am. Soc. M. E. (by letter), said that, in his opinion, when speaking of a boiler we should consider the unit for steam generation as a whole and not divide it into its elements, as stoker, setting, and steam container; and from this point of view we can lay claim to some very good and definite improvements. The improvements in efficiency, of course, result most directly from the method of furnace construction, baffling, draft conditions, etc. In a mechanical way, stokers are constructed with due regard to reliability, and in forms suitable for various grades and kinds of coal. The quality of fire brick has been improved for withstanding the higher temperatures due to higher drafts and the increased rate of combustion resulting from this increase in draft. The improvement in the general setting of the boiler by the use of magnesia in the walls and the steel casing gives a tighter setting than the old all-brick setting, and vastly more substantial and less costly to maintain.

The increase in size of boiler units has probably been the result of the enormous capacities possible in the construction of single turbine units, and which has necessarily resulted in a decrease in the operating and maintenance expense and in a better condition generally in the boiler room.

So much is true of boilers for large central power stations, but on the other hand the enormous number of boilers in small isolated and industrial plants, of too small a size to warrant investment in coal-

§ Chief Engr., C. C. Moore & Co., San Francisco, Calif.

* Ch. Engr., Union Elec. Light & Power Co., St. Louis, Mo.

handling apparatus and mechanical stokers, are today practically without change from those of a generation ago. A feature that Mr. Pratt did not mention, and which is particularly applicable to the smaller-sized boiler plant, is the use of the down-draft furnace. For efficiency of operation and to eliminate the smoke nuisance from our cities, this type of furnace is ideal where bituminous coal is used and where the boiler plant is of such size that hand firing is more advantageous than stokers. In fact, to meet the requirements of the present smoke abatement laws, the down-draft furnace is almost indispensable. Mr. Hunter.

The subject of the rating of boilers is one which should have more careful consideration from engineers in this country, and which is, sooner or later, destined to come up for some kind of action. Boiler rating and boiler capacity actually developed are in no wise the same. We have been content to call a boiler horsepower 10 sq. ft. of heating surface, and we now find ourselves speaking of boilers as developing 200% or more of their rating. Such conditions seem radically wrong and it seems absurd to go on reckoning the output in percent of a certain rating when the output is expected to be about twice the stated rating.

The steam turbine quickly developed a condition whereby it is now rated for a maximum load under the conditions for which it is designed. This he thought was the logical method, and at such rating it is known just what our apparatus is good for without always having to remember the possibility of overloading. Some such similar condition should prevail with steam boilers.

In steam boilers, however, two conditions must be considered: first, the larger size boilers now being installed in central stations, and from which capacities upwards of 200% of their normal rating, as at present stated, are obtained; second, the smaller boilers installed in industrial plants operated by hand firing, and under which condition equally high capacities are not obtainable. A statement of boiler rating should convey clearly the working capacity of a boiler unit, and at the same time should carry with it an idea of the relative size, whether referring to a small or a large unit, the latter purely for commercial reasons in order that comparisons may be made as to price, etc.

Ten sq. ft. of heating surface as a measure of one boiler horsepower is purely an arbitrary figure. It really means nothing, as the corresponding capacity to be developed, according to the rule for evaporation, as we now use it, is 34.5 lbs. water from and at 212°. The actual capacity to be delivered is subject to several variable quantities, as rate of combustion, heating value of coal, force of draft and cleanliness of the boiler. Then again, while it appears that our present rate of 10 sq. ft. of heating surface per boiler horsepower is illogical, yet on the other hand boilers are not usually designed for any given set of conditions, quality of fuel, etc., and it would seem that a uniform basis of rating, by reference to the actual capacity to be obtained, will be somewhat difficult to obtain. The fact remains, however, that boiler operation is not expressed in the most satisfactory terms and consideration should be given the matter

Mr. Hunter. with a view to standardizing in a logical way the unit of power by which we express boiler operation. He was not attempting at this time to offer a solution to this question, for he felt that it is a matter upon which discussion should be invited from our engineers and a movement put under way to remove what Mr. Pratt has very aptly expressed as "a widespread agitation against such an irrational method of rating the power of boilers".

Paper No. 127

EQUIPMENT, PROCESSES AND METHODS FOR THE BOILER SHOP.

By

E. C. MEIER
Heine Safety Boiler Co.
Phoenixville, Pa., U. S. A.

In treating this subject it seems best to go back and note the more important improvements which have been made in boiler shop practice during the past 25 or 30 years.

In the early days there were three kinds of shops, namely, those which built boilers for sea-going and lake-going vessels, located in the different sea-coast towns and lake ports, where the boilers were built more or less following the Scotch marine practice and where heavy metals were handled; the locomotive shops, located mostly in the large cities in the East, which built principally boilers for locomotives; and the boiler shops of the Middle West, located along the navigable rivers, where boilers for flat-bottom river steamboats were built.

Of course, throughout the country there were a large number of smaller jobbing shops, but it is safe to say that the improvements in equipment and methods were generally made in the marine and in the locomotive shops. There was not much flanging done in the river shops nor the jobbing shops, except such as was done by main strength and the skill of the mechanics in wielding hammers, nor did any of these shops give much consideration to the heat treatment of the metals they were working.

The marine shops and the locomotive shops, having to deal with higher pressures and thicker metals, and having more difficult flanging, naturally equipped themselves with tools for doing this heavy work, and these were mostly hydraulic tools, a large number of which came from England.

In the earlier days, the jobbing shops and river shops did very little drilling and reaming, and also very little planing, and relied chiefly on the punching of holes and drifting them into alignment, while the chipping and caulking of plates was all done by the skillful use of tools in the hands of workmen that had grown up with the work, having started in at heating rivets and picking up bolts about the shop.

With the tendency towards higher pressures, which for land practice began about 30 years ago, there developed a necessity for better workmanship and better handling of materials. It soon became apparent that larger capital was needed to put in the proper equipment to handle this class of work.

It is strange, but in quite a large number of the operations in boiler building there has been no very great improvement in the machinery. Especially is this so in the punching process. It also became necessary to devise means for handling the heavier materials which were constantly being used in the building of boilers for heavier pressures.

In the year 1900, the writer was instructed by the Heine Safety Boiler Co., of St. Louis, Mo., to design and build a shop in the East which would enable them to perfect their boiler, as well as increase their output and reduce their cost. Several shops throughout the East were visited and it was found that the majority of them had not been especially designed for the particular product which they were then building; and in a great many cases there were unnecessary movements in the transporting of material from one tool to another. It, therefore, appeared that the problem of general arrangement of the shop was probably more important than any other single point to be considered. The question of location was the first matter taken up, and in working this out, the conclusion was reached that the shop, in order to properly serve the eastern part of the United States, should be located within 10 or 12 hours' travel by freight from steel mills. Also it must be located on the main line of some good railroad with plenty of switching facilities, and also in a neighborhood where good mechanics and good material for making mechanics, could be obtained. A location was secured with a frontage of about 1500 feet along the main line of the Philadelphia & Reading Railroad at Phoenixville, Pa., a

town which had been known since the days of the Revolution for its mechanics and good, hard-working citizens.

The general plan of the shop adopted was in the form of the letter ''E'', thus giving opportunity for future extensions in five directions, the original shop being the center. The first thing to be considered was the particular type of boiler to be constructed. This should always be considered in designing a shop, and the different parts necessary to build a boiler should be analyzed, and the tools and transportation facilities arranged accordingly. Railroad sidings were laid out so that the cars of raw material could be brought directly into each one of the four shops composing the letter ''E'', and in this manner the raw material could be placed nearest to the point where it was to be used.

There did not seem to be much new in the way of machinery, with the exception of air tools, which were then beginning to be introduced. Accordingly a power house was laid out which would produce electrical power, direct steam power, hydraulic power and compressed air; and these different classes of power were separately connected to each of the four shops so that any one could be run independently of the others. This enables any one shop to be run overtime to bring its product up to a balance with the production of the others.

One of the essentials is a large, high, well-lighted erecting shop suitably served by overhead traveling crane, and without any of the larger tools in it to interfere with the assembling, fitting up and finishing of the boilers after the other shops have produced the different parts.

A large building parallel and connected to this erecting shop was set aside for the storage of finished material, so that the erecting floor could be relieved as soon as the job was done, if the shipment was not desired by the customer at once.

Another building parallel to this was set aside for the receiving of heavy plates, tubes and other parts which were required for the finishing of the boilers, and in this building were located the various punches, shears, planers and laying-out benches. Suitable racks were erected to enable the different classes and different shipments of raw materials to be kept separate, so that any particular plate or lot of tubes could be used for any particular job without rehandling.

The other three shops, comprising the three legs of the letter "E", were divided into the machine shop, sheet-iron shop and flange shop. These shops have the duty of preparing the parts and delivering them finished and ready for the final erecting in the erecting shop.

In building boilers on a large scale, it appears to be necessary to have plenty of room, so that different jobs can be jumped ahead of others when the question of final delivery requires it, and, therefore, to avoid congestion, the shops were spread over quite an area. This brought up the problem of transportation, it being necessary to transport material from one shop to another with the least amount of labor; because, as before stated, the machine operations in boiler building were not very much improved, and, therefore, the saving, if anywhere, must be obtained by quick and cheap transportation. The buildings were made of heavy structural steel, so that "I" beams, trolleys and traveling cranes could be suspended from the roof trusses in any part and in any direction. Some of these cranes were electrically equipped, some equipped with air motors, and still others with one-hand operating devices. The route of the material from the unloading, all the way through to the finished product, was a thing to be carefully studied, and the cranes and trolleys were arranged so that it was possible to handle a piece of material from one part of the shop to another without it ever having to touch the ground. The tools were then located in such positions that, as the plate went forward from the laying-out tables, it moved in a continuous direction to each individual punching, cutting, planing or bending tool, always progressing towards the final finishing or erecting shop.

It was found that certain parts of the boiler required extra work in the shape of flanging, drilling and reaming, and, therefore, a dividing point was made, allowing such work as was purely cylindrical and conical to take a direct path to the erecting shop, while the other material branches off on a "Y" system of trolleys leading directly to the flange shop.

As before stated, in the boiler shop proper, the tools used in the production of cylindrical and conical work are practically the same as they have been for years, with the exception of some minor improvements.

In flanging, it was found that great improvements could be made; hence suitable hydraulic machinery was provided, in part by purchase and in part by design and construction, so that every part of the flanging could be done by hydraulic pressure without a hammer having to touch the material. This materially lessened the tendency towards crystallization which formerly took place, due to the repeated hammering in hand flanging.

A study was also made of the material employed, and every process was arranged so that it could be completed without the metal reaching a lower temperature than that of a good red heat. The heating processes were studied, and it was found that good coke fires with a certain amount of wood were easier on the metal than the former coal fires. Therefore different-shaped fire places or forges were built, each one of them shaped to give heat to the particular part and shape that was to be flanged. It was also found best to remove all strains from the plates after being flanged, and a large annealing furnace was built, into which all plates, after the flanging had been accomplished, were put and brought to a bright yellow heat, and then straightened and annealed so that all internal stresses were removed from the metal.

It was also self-evident that in building large numbers of boilers of the same size and design, standardization was an essential feature, and for this reason heavy cast iron templates and forms were made and machined, so that each part after flanging could be set to fit a standard form. In this way that particular part of any boiler was a duplicate of the same part of any other boiler.

It was also planned and worked out that another fitting should not be necessary in the erecting or finishing shop, and that if for any reason a part should leave the flanging shop, and come into the erecting shop in such a condition that it would not fit, it was sent back to the flange shop to be properly fitted, where they had the facilities for heating and fitting, without resorting to the old method of building fires alongside of the boiler, or of using hot plates and then straining the metal into shape. This point has borne fruit in the small percentage of losses due to cracking, which in the old boiler shops was a source of continual loss. This method could only have been carried out by the aforementioned proper handling facilities, so that the cost of taking a

part back to the flanging shop was too small an item to cause a material increase in expense.

The next thing given consideration was the avoidance of leaks in testing, by having the work properly finished before going to the finishing shop, and this with special reference to the riveting. Hence it was found advisable to resort to drilling and reaming as much as possible, and naturally this increased the cost. On this account it was found desirable and feasible to put the drilling and reaming under the control of skilled machinists, by transporting all of this class of work into the machine shop and then back into the erecting shop. It was found that the drilling and reaming would be better carried out under the refining influence of the machinists than it could if the drill presses were located in the boiler shop, where they came under the influence of a rougher class of mechanics.

Here, again, it was found that there was no very great improvement in drilling machines, and that the best plan was to get heavy, massive drill presses without tables, and to build under them suitable tracks and heavy cars so that the work could be moved easily, instead of swinging the heads of the heavy drill presses. High-speed steel was found to be economical, even if it did cost a great deal more than ordinary steel. With the use of high-speed steel, however, it was found necessary to have a suitable lubricating system, so that the individual workman was not called upon to dip material from a bucket and put it on the tool whenever it smoked. Accordingly a pit with suitable pumping device was installed, and under the small tracks that served the drill presses, large concrete basins were built, so that any lubricating fluid that was spilled ran back to its source of supply, and thus there was no occasion to stint the amount of lubricating fluid used.

After the above processes were worked out it was found that a different grade of men could be employed than that formerly constituting the employees of a boiler shop, i. e., it was found that having divided the processes, it was perfectly possible to train up a raw beginner so that he would become an expert on one operation, and by passing the work from one man to another, the shop was enabled to get the best of each individual man, and the work was gradually improved and standardized and the cost reduced.

This was especially true in all of the shops which fed the main finishing or erecting shops.

It was also found that a more satisfactory method of supplying material to the different workmen was needed, as well as a better method of keeping time and costs. For this reason a store room was arranged convenient to the railroad as well as to the wagon road, so that it could be supplied with materials from the railroads or automobile trucks. This storeroom receives everything and stores it in quantity, issuing to a serving room such things as are needed by the different shops. Each shop foreman is supplied with order blanks, and he issues orders on the serving room for the material he wishes, giving the number of the job and the quantity required. These order blanks after having been filled by the serving room and delivered to the different workmen who require the material, are then turned into the office, and become a part of the cost clerks' records.

A ticket system was also installed, a suitable ticket being designed, giving on the face side the different places for stamping the time, and on the other side the different parts and the number of pieces, so that the foreman could issue these tickets to a workman with the least amount of pencil work, it being only necessary to write a few figures and a few check marks to fill in the printed form. The foreman, on seeing that a certain workman or gang of workmen are very nearly through with their operation, issues other new tickets, explaining to them what is to be done. Immediately upon completing the operation they are working on, they take these tickets to the nearest clock, stamp the old ones out and the new ones in. Thus there is no elapsed time from one job to another, and each individual job shows its true labor cost. If such a thing as loafing on a job occurs, this particular job is charged automatically on the time-clock system with its loafing as well as its production work, and the foreman would then have the matter brought to his attention. There is no question of the favoritism of some timekeeper working on the same job, or of a certain workman running up the cost. The system gives the foreman an opportunity to see the tickets, and is of great advantage to him in handling his men. Tickets frequently come in for jobs lasting as short a time as five minutes, which before this time-keeping system was inaugurated, would have

been charged to some general account by the time-keeper, and in that way an untrue cost would have developed, which would mislead the office in making future estimates.

The transportation system above mentioned was placed in charge of one gang of men with a foreman, and the cost of this transportation was pro-rated daily among the jobs that participated in it. Thus the individual workman did not have to do transportation work to the detriment of his better production on his individual job.

Finally, going to the erecting or finishing shop, the riveting apparatus, both hydraulic and pneumatic, is installed in this building, as well as a suitable supply of modern air tools, and also the now very necessary oxy-acetylene welding and cutting apparatus. Here under one foreman the different boilers are assembled out of the parts supplied by all of the other departments, and after they are finished they are turned over to the testing department, where the final testing and inspection takes place. Here, by mounting the work on high blocks, the testers and inspectors are able to crawl all around, as well as underneath, to look for different minor defects, and ample light and inspection facilities are given so that when the work is finally finished and ready for shipping, all defects, if any, have been discovered and remedied.

By suitably arranging the multiple hydraulic system, it was found an easy matter to keep any desired test pressure on a boiler for any length of time required, instead of the older method of pumping up, and, the instant the desired pressure had been reached, stopping the pump. By thus maintaining the desired pressure, the inspectors have plenty of time to thoroughly search out all places.

After the testing department has finished its inspection, the boilers are moved by electric crane to the large store room mentioned in the beginning of this article, and here the shipping department takes hold of and prepares them for shipment, gathering together the different extra equipment required in each case.

It was found difficult to apply piece work to all parts of a boiler, and it was decided that piece work could be employed to advantage only on such parts as might readily be inspected, not only while building, but after the boiler is completed. As a re-

sult, no piece work is used on any part which will be in any way hidden. Piece work can readily be employed in the manufacture of the various parts that go to make up a boiler as a whole, but it is far better to rely on good tools and good work, and on so dividing the operations that each man gives his best efforts to one particular operation, and on the clear understanding that any of his work which does not come up to the standard in the next department will be sent back to him for correction. It is found that a better grade of work results, creating a form of friendly rivalry which tends to increase the output as well as to lessen the percentage of errors.

To sum up, it may be stated that the main essentials of a modern boiler shop, with the present available equipment, are: plenty of room, an abundance of good light, natural and artificial, plenty of ventilation and plenty of handling facilities, both overhead and on the ground. It may be here noted that the entire overhead handling facilities have been duplicated by miniature railway systems, so that if any part of the overhead transportation gets out of order, nothing is interrupted, as the railway tracks answer the purpose while repairs are being made to the overhead. This, of course, makes an extra investment, but is justifiable in a large shop where production is an important item.

The distribution of tools and machines so that workmen are not required to travel any considerable distance to reach the tool they want, ample switching facilities, a well equipped storehouse, and a good automatic timekeeping system are essential. Then, regarding the tool equipment, this should consist of the best tools of each kind that can be obtained on the market, and of size and weight heavier than may seem necessary, in order to avoid breakdowns.

The distribution of power throughout the shop has been greatly improved since electrical transmission has been so much perfected, and by having individual tools motor-controlled, the percentage of accidents to workmen has been greatly reduced.

It may be also noted that a system of order slips showing each foreman not only what he has to make, but what he has to obtain from some other foreman, greatly facilitates the movement of the work through the shop, especially when each foreman has

a telephone at his elbow, whereby he can call up another part of the shop and hurry up such parts as are required.

Automatic machinery has not, to any great extent, helped boiler shops, with the exception of the production of minor details, so that a boiler shop must rely on quick transportation as well as on the fellow feeling of one department for another, and on developing the spirit of working for the common good of the shop as a whole. This can only be realized by proper encouragement on the part of the management.

One feature which was found to advance this feeling was never to countenance the hiding of defective work, but rather to encourage all men to show up defective work by letting it be generally known that no man was to be condemned or censured for making a mistake, provided the mistake was immediately shown to the management. In other words, the practice of docking men when a mistake has been discovered tends to encourage these men to hide bad work, and also to encourage their fellow men to help hide the work rather than see one of their fellows suffer. I consider that one of the most important elements in the equipment of a modern shop is the assurance of a "square deal" on the owners' part, and thus to be assured of a "square deal" to themselves.

The personal welfare of the men must be considered, giving them suitable places for washing and other toilet facilities, as well as suitable metallic cupboards for keeping their clothes, lunches and other personal effects. They should also be discouraged from taking risks or from exposing others to risks, or the chance of accident in any way. It was also found that the establishment of a "sick bay" produced a good effect on the personnel of the shop. To this end one room in the office was fitted up with a sanitary flooring and plenty of light, and washing facilities. It was kept locked and the key in charge of one of the men in the office. One of the men in the office was given a course of training in "first aid" and a suitable medicine chest was kept filled with standard prescriptions obtained from a well known physician, and a good quantity of antiseptic washings and dressings kept on hand so that first aid could be administered. To the antiseptic treatment of all cuts and wounds, many a man in the shops owes his quick recovery from minor accidents as well as

the avoidance of blood poisoning. Arrangements were made with a local hospital for taking care of serious cases, and by always having an automobile in readiness, we succeeded several times in saving men's lives by getting them, in less than five minutes' time, from the shop to the operating table of the hospital. This in itself has a wholesome effect and shows the men that consideration is given to their welfare, as well as to the amount of work they can produce.

Another point was to let it be generally known that any man who could improve on a process, or could perfect some little shop wrinkle that would result in cheapening or bettering the work would be rewarded financially, and this has resulted in several important improvements. In fact, with all the different tools to be selected from, tools that absolutely fit the work are rarely or never found, and, therefore, with proper encouragement, a number of special tools and wrinkles have been developed, insuring a great saving, and which are not readily obtainable on the open market.

The general understanding that suggestions are always welcome, and that workmen can get the ear of the management without going through any red tape, tends to improve the personnel, and settles many a question, which if not adjusted in time might develop a feeling of unrest and distrust, and which might ultimately bring about an open rupture or strike. The experience of this particular shop of having had only one strike in 15 years, and that only in the beginning of its career and before the different systems above outlined had been perfected, gives proof that the mutual discussion of all problems works to the great benefit of the owners of the shop as well as of the workmen. This has been frequently illustrated when, owing to general business depression and slack times, the shop felt that the reduction either of forces or wages was imperative. In such cases the management did not peremptorily lay off men, but put it to a vote of the workmen themselves, either to take less money or keep the same wages and lay off certain men, the management to abide by the vote of the men; and it was generally found that they were fair in their decisions. Sometimes it was found better to give them turn about, laying off certain men one week and the next week allowing them to work and laying off others. In this way the

men were satisfied, and there was no difficulty in keeping the men, or in obtaining others when business increased.

Another point is in keeping track of the individual material that enters into every individual boiler. As soon as the steel plate and other material is unloaded it is given a serial number, so that each individual piece of steel that goes into a boiler has its serial number, and by carefully keeping a record in the office of these serial numbers and pieces of material, it is possible to trace out which particular workmen worked on a certain part of a particular boiler, and also to reach back to the steel mills and tube mills, showing them, in case of defects developing, what particular heat and order the material came from. This involved considerable extra cost, but was a benefit to the workmen as well as to the customers and the inspectors from the different departments of the Government and insurance companies. Private corporations appreciate this feature, and have often so expressed themselves. Here, again, it may be noted that without ample handling facilities this would be almost an impossibility.

To sum up, we might follow the route of the material from the receipt at the railroad unloading crane to the finished boiler delivered to the cars. The plates, tubes and other material receive their serial numbers, and are placed in racks and bins by the transportation department under the guidance of the receiving clerk or head of the store room. An order is issued to the general foreman, who in turn directs the layer-out to pick the material from the respective racks, lay it out, pass it through shears, cutting it to suitable sizes, and doing whatever punching is necessary, and then passing the work to the flange shop for flanging. The work which requires no flanging is passed by him directly to the men who punch the rivet holes and plane the sheets and roll them into cylinders or cones. They are then transported to the machine shop, where, under the drilling and reaming presses, all rivet holes are reamed out true and fair, whereupon they are passed to the finishing or erecting shop, where they wait the arrival of other parts, which, as above stated, went to the flange shop direct. In the flange shop the plates are flanged to their different shapes under the hydraulic machines by means of suitable and specially designed dies. They are then fitted up and matched together, and then taken apart and run

into the annealing furnace. After being annealed they are again assembled in the flange shop and passed on to the machine shop, where the holes are reamed to the true size and the parts that require tapping are tapped, the necessary staybolts inserted, and everything trued up. Then they are passed on to the erecting shop, where they join the cylindrical and conical parts above mentioned. Here the different parts are "fitted-up" and the final assembling takes place, and the internal fittings and other appliances which have been made in the sheet-iron shop are brought to the proper place, where the fitters install them into their proper positions. The work is then passed on to the caulkers, where with suitable round-nose caulking tools, run by air machines, the entire work is caulked, and then passed on to the testing department, which after applying the proper pressures and searching out for leaks and defects, finally perfects the boiler and turns it over to the shipping department. Here it is either put directly on the cars, or if the shipment is not immediately desired, is passed on to the large store room to await shipping orders. The machine shop, in the meantime, has finished up the different fire fronts, grate bars, steam connections, and other fittings and turned them over to the shipping department in the large store room, ready for loading with the boiler when it is shipped.

It is found by properly timing the different operations, and by the mutual coöperation of the different foremen, that the flanging work, which takes a longer route, arrives in the finishing shop at practically the same time as the cylindrical work, the latter having been started a certain number of days or hours later. With the above equipment the turning out of one boiler per day has been accomplished several times, and in fact, in one particular instance a test case was made, and two (2) 300 hp. boilers were built from the raw material to the finished work in exactly 60 working hours. In this case, of course, they were given precedence over all other jobs and had the right of way through the shop.

With an equipment as above described, ten-day deliveries are easily made when all the information is in the hands of the shop before the work is started.

When it is stated that the two above mentioned boilers

were built in 60 working hours, and that 10-day deliveries are easily made, this might be misleading without the following explanation:

One feature developed by this shop is the distinction between ''Boiler Making'' and ''Boiler Manufacturing''. In a boiler-making shop everything is done on one or two sets of boilers until they are finished, and then another one is begun. In a boiler-manufacturing shop, such as the above described shop essentially is, a large number of orders are worked upon simultaneously; that is, the different processes on a large number of orders are grouped, and it is perfectly possible for the flangers to be working on a dozen different boilers in one day, and yet none of these boilers is finished. Those operations where certain dies would do work on similar parts of different sizes of boilers are grouped, and the parts of many boilers are held back, so that the whole number can go through the one operation and thus avoid the expensive change of dies. Presumably the next day the same dozen boilers will go through another operation, and so on, until the different parts come to a point where they begin to show their own individuality, and from then on each boiler stands on its own footing and works through individually to the erecting shop. It is no uncommon thing to have as many as 150 different boilers going through these shops at one time, all of them receiving some work, but in a very few days they begin to take their places as individuals at the lower end of the erecting shop, and from then on advance in accordance with their order dates. At various stages in the building of a boiler, if the order dates are changed, it is possible to jump certain of these operations ahead of others, and in this way quicken a delivery that was planned for a later date. This method of grouping work gives a further opportunity of using each workman on the job for which he is best fitted; but it also involves considerable labor on the transportation department and coöperation on the part of the foremen to see that no particular order gets lost and drops behind its date or loses its status on the way to the erecting shop. Once assembling is begun in the erecting shop, the boiler must be finished and taken care of in the store room, or shipped; otherwise, the erecting shop would quickly become

congested and all deliveries be interfered with. These points can only be carried out when a shop is making one particular type of boiler, even though numerous different sizes are being built.

From the above it is readily seen that a lack of operations would readily cause a serious interruption and throw the entire outfit out of balance; and for this reason, a certain amount of stock is always carried forward together with orders, so that each individual workman is always assured of plenty of his particular kind of work coming along. This stock is a good asset, because it very often helps in making very quick deliveries, and in such cases orders may be secured which otherwise would have been lost.

As a case in illustration, a large rolling mill had a boiler explosion at midnight on a certain date. The management of this rolling mill got in touch with our management at 2 o'clock in the morning, an order was signed for 1500 hp. of boilers, and inside of 10 hours these boilers were being moved towards the rolling mill plant by the railroad, and in just one week's time from the date of the explosion the rolling mill was running.

On other like occasions the stock pile has not only proved to be a balance wheel to keep all operations working, but a source of great revenue as well.

It was also found that certain classes of general tank and heavy sheet-metal work could be taken to fill in, and this was very often taken at low figures, but the cost of the boilers in progress at the time was kept down by having these orders for "fillers in", thus keeping all the machines and processes busy. The sheet-iron shop was used as a general contracting shop, and it was found practicable to pick desirable work to fill in the regular work of manufacturing findings for the boilers. It is thus seen that another important factor in a modern boiler shop is to always have the shop well filled with main orders and at the same time with such supplementary work as will fit in without interrupting the regular processes on the standard article being manufactured.

This particular shop, working on the above general plan, has been so successful that in 15 years it has never had a general shut down. Wherever possible, tools are duplicated, so

that no process is delayed by breakdowns and the repair department does not have to work at nights or on Sundays. Another important point is to have a large margin of safety in all tools, especially in all hoisting and transporting cranes, trolleys, etc. In addition to this, during the Christmas and New Year holidays all chains were removed from hoists and annealed and carefully inspected by the blacksmiths and all machinery and tools were gone over and given an annual inspection, so that when the new year began the shop was ready to start out in as good a shape as ever.

Another thing inaugurated was a regular Saturday clean-up made by a gang of 10 or 12 men with a foreman, and this in time became the duty of the transportation department. They begin at noon Saturday, when the regular shop shuts down, and clean every nook and corner and every floor from one end of the shop to the other, sweeping the floors, gathering up any rubbish and scrap, burning the rubbish and storing the scrap in bins. It was found by proper classification of the scrap that a 25% better selling price resulted, and the sales of scrap became a large and important item.

All oils, paints and grease are kept stored in a suitable vault quite a distance from the plant, and never more than one gallon of each particular kind of oil or paint is allowed in the shop. This reduces the fire risk very materially. During this Saturday clean-up, all bolts, rivets and other articles that might have been carelessly dropped during the week are gathered up and re-sorted into the store-room bins, and in this manner quite a saving is effected. Such bolts as are found to be defective are sent to the threading machines and re-threaded and put into the store room to be used as fitting up bolts.

After the annual inventory has been taken each year it is gone over carefully, and such parts and findings as are found obsolete, due to changes during the year, are promptly scrapped and converted into cash, thus effecting another saving, all of which tend toward the reduction of cost, as well as improvement in manufacturing processes.

Paper No. 128

COMPRESSED AIR IN THE ARTS AND INDUSTRIES.

By

W. L. SAUNDERS, Pres. Am. Inst. M. E.
Mem. Am. Soc. M. E., M. Am. Soc. C. E.
Pres. Ingersoll-Rand Co.
New York, N. Y., U. S. A.

Compressed air in its employment is a potent agency in the industrial development of the world. The annual production of fifty million tons of steel is dependent upon its employment in the furnaces, cupolas and Bessemer converters, in smelting the ore and in its conversion to a form, as iron or steel, adapted to industrial uses. In smelting the ores of iron, approximately 125,000 cubic feet of free air is used in the blast for each ton of iron produced from the blast furnaces. This great volume of air and the additional quantities used in changing the iron into steel, and the air consumption entailed in smelting and working other metals and their ores and in the general processes of combustion, would in the aggregate give a volumetric quantity of gas that would in time make the surrounding atmosphere unsuited to the maintenance of animal life were there not corrective agencies at work in nature, which reconvert the noxious gases to a condition of normal atmosphere. These immense volumes of air must be, by some means, compressed and given the expansive force requisite to their employment. It is manifest that the compression of air and the means employed in accomplishing it are of the essence, an indispensable part, of the industrial and commercial progress of the world.

COMPRESSED AIR IN METALLURGY.

With the establishment of the Bessemer process began a new era in the industrial progress of the United States, Great

Britain, Germany and other metal-producing countries. The forcing of compressed air through the molten metal in the converter, and the consequent decarbonizing action, have made this method of steel-making possible of accomplishment. To the basic Bessemer process has been attributed, in great part, the rapid industrial development of Germany; through this process it has been practicable to utilize the immense deposits of low-grade iron ore known as ''Minette''—a contemptuous diminutive applied to it in the past by the French. All metals when exposed in an inert atmosphere to a sufficient temperature assume the form of liquids, the liquids passing under higher temperatures to vapors. They are generally, with some flux, exposed to the action of fire; the fire in most cases having a chemical, in addition to its physical, function. The furnaces are designed to facilitate the action of the heat and carry the furnace gases in the desired direction, the intention being either to burn away certain components of the ore or to reduce (deoxidize) the ore, when the draft must be restricted so as to keep the ore wrapped up in combustible flame gases (carbon monoxide, hydrogen, marsh gas, etc.). Metal-reducing agents other than those contained in the blast or fire are only exceptionally employed.

COMPRESSED AIR IN MARINE PRACTICE.

To the forced draft in the boiler fires of vessels may be, in part, attributed the high power developments in restricted space for boiler capacity, as illustrated in naval practice, in torpedo boats, destroyers, etc. In closed stoke holds, in which the only exit for the air is through the chimney, the air is driven into the stoke holds by fans in order to maintain a pressure above that of the atmosphere. As used in war vessels and some fast passenger vessels, pressures of one to one and a half inches of water are usual, but four inches is sometimes used in torpedo or similar craft. The Howden system of forced draft, which is quite generally employed, uses air under pressure above and beneath the fires, air being forced into an enclosed ash pit as well as into the furnaces to ensure more perfect combustion. With natural draft, the approximate combustion is 15 to 20 pounds of coal per hour for each square foot of grate area; with

forced draft 20 to 35 pounds to as much as 70 to 80 pounds in torpedo boats.

FORCED AIR CIRCULATION: FORMATION OF COMBUSTIBLE GASES.

Formerly, artificially produced currents of air were used only to assist the combustion of fires or furnaces; now this is but part of their purpose. Bellows, rotary fans, blowing engines, rotary blowers, steam jet blowers and other similar appliances are now used in the ventilation of mines, of buildings and generally in the removal of vitiated gases and in the supplying of gases and air for chemical purposes. Appliances of this kind differ from air compressors in that they are primarily intended for the transfer, at low pressures, of quantities of air, whereas the function of the compressor is understood as the production of highly compressed air. The bellows, as applied to industrial purposes is referred to by Boyle in his ''Sceptical Chymist'', as illustrating the practice of iron smelting in his time, ''I remember I have observed too in the melting of great quantities of iron out of the ore, by the help of great store of charcoal (for they affirm that sea-coal will not yield a flame strong enough) that by the prodigious vehemence of the fire, excited by vast bellows (made to play by great wheels turned about by water) part of the material exposed to it was, instead of being analyzed, colliquated, and turned into a dark, solid and very ponderous glass, and that in such quantity, that in some places I have seen the very highways, near such iron works, mended with such lumps of glass''. Blowing engines find their use where higher pressures than can be supplied by a fan or blower are needed, as in blast furnaces or Bessemer converters. These engines are built either horizontal or vertical and are in form and action similar to the standard reciprocating air compressor, the air being compressed by pistons or plungers in a cylinder that is provided with inlet and outlet valves (suction and discharge). Formerly, blowing engines were single acting, that is, compressing air but on one side of the piston in the air cylinder; the practice is now to make them double acting. Engines of this type are usually steam driven, but gas engines, utilizing what formerly were wasted furnace gases, are now quite generally used where these

gases are available. About the end of the 19th century this important development in power economy, by utilizing the waste gases, took place. The waste gases from the blast furnaces form, with a proper admixture of air, an explosive mixture which is used in driving the piston in the actuating cylinder of the engine. Since the majority of blowing engines are employed to provide the air in iron blast furnaces, great economies have resulted in the use of what was formerly a waste product. Blowing engines of very heavy design are in general use in Great Britain; the air cylinders are of great size, an engine built in 1851 had an air cylinder of twelve feet in diameter (bore) with a stroke of twelve feet, giving a discharge of 44,000 cubic feet of air per minute, delivered at a pressure of four and one-half pounds. A large blowing engine is described in Engineering (Jan. 6, 1905) as having cylinders of ninety inches in diameter and a stroke of seventy-two inches, and with a capacity of 52,000 cubic feet per minute, delivered at a pressure of twelve and a half to fifteen pounds per square inch.

AIR PRESSURES IN BLAST FURNACES.

The pressure of air to be supplied by blowing engines depends upon the purpose for which it is to be used. In charcoal furnaces the pressure is low,—less than 1 lb.; in blast furnaces using coal, four pounds pressure is common; in American furnaces where anthracite coal or coke is used, ten pounds or over; in the Bessemer process of steel making, twenty-five to thirty pounds is usual. The practice in Great Britain and on the Continent is to supply the blast for a number of furnaces from one large engine; in the United States each furnace has its separate engine or blower. In Germany and other parts of Europe, in recent years, these heavy and cumbersome blowing engines are being replaced by centrifugal blowing machines, turbo-compressors and blowers, where the required pressures are attained by successive stages of centrifugal compression, the air being forced from one stage to the succeeding one as the pressure is augmented by the great speed and centrifugal effect obtained from the impellers in this design of compressor or blower. These machines are being increasingly adopted in this country as their merits are becoming more generally understood.

The turbo-compressor is made for any air capacity, to deliver 3500 to 5000 cubic feet per minute at 100 pounds pressure, or in the larger units the turbo-blowers will deliver 50,000 to 60,000 cubic feet per minute at 30 pounds per square inch.

FANS AND ROTARY BLOWERS.

The blower may be said to occupy a position intermediate, with respect to pressure, between the fan and the blowing engine. Their field is where large volumes of air are required at pressures lower than that supplied by the blowing engines. The blowing engine draws in, compresses and delivers its air by the action of air-tight pistons in a cylinder. The same effects are in a manner attained in the rotary blower, with the difference that the pistons revolve instead of reciprocating, as in a cylinder. This form of compression is associated in America with the names of Baker and of Root and with the machines designed upon the principle of their original machines. The flow of air through these machines is continuous and therefore valves are avoided. Machines of this general design deliver from 25 cubic feet per minute to 25,000 feet or more, and in single stage deliver up to pressures of 3 pounds. The clearance essential to the free working of machines of this type makes higher pressures uneconomical because of the great leakage; higher pressures may be obtained by working two or more machines in series, the pressure being raised in steps. The fan is now used in the blowing of forges, supplying the blast in foundry cupolas and furnaces, for the forced draft of steam boilers and for other purposes where very large volumes of air or gases are to be given motion or circulated by low pressures. The revolution of the vanes in the fan causes the centrifugal effect by which there is diminution of pressure at the center and increase towards the periphery and casing, the air in consequence circulating from the center outward, the pressure depending on the peripheral speed. In the smaller sizes the mechanical efficiency is very low; in the larger sizes (5 feet and over) 70 per cent may be obtained. Maximum efficiency is, at a predetermined speed, anticipated in the design of each fan. To move comparatively large volumes of air at pressures but little above the atmosphere the fan is

most suitable; where the pressure is above one quarter of a pound to the square inch the waste of work is so great as to preclude their use. Large fans, of forty or fifty feet in diameter, are used for the ventilation of mines, and have developed efficiencies of 75 per cent, and in some special forms 95 per cent has been attained. The sirocco type, having a large number of very narrow vanes, when measured radially, but long axially, can be made in smaller diameters, for the same output of air, than the older designs,—a great advantage in situations where space is valuable or restricted. Air propellers, screw or helical blowers are employed where large volumes of air are to be circulated, where there is but slight resistance to their movement, as in rooms or buildings.

PNEUMATIC PRESSURE IN SUBMARINE WORK.

Diving apparatus, bells, caissons and tunnel shields now play a most important part in the field of engineering. Amongst the ancients, divers were employed in work that is somewhat analogous to their employment in modern times. It is recorded that 1000 years before the Christian era the art of diving was employed commercially and in engineering. During the siege of Syracuse divers were used to saw away protective barriers to the harbor entrance; these barriers were below the surface and were for the purpose of damaging the Greek ships. At the siege of Tyre, Alexander the Great used divers to destroy the submarine defenses of the besieged. The Rhoadians had a salvage scale for divers; the recovery of wrecked materials from depths of 24 feet entitled them to half the property value recovered, at 12 feet a third and at three feet a tenth. The earliest mention of artificial aids or apparatus in diving is by Aristotle, who mentions that divers are provided with instruments for respiration through which they can draw air from above the water and also that divers let down a metallic vessel which does not fill with water but retains the air beneath it. It is recorded that Alexander the Great descended into the sea in a machine called a ''calimpha'' which had the power of keeping a man dry and also admitting light. Pliny refers to divers engaged in the strategy of ancient warfare who drew air through a tube. Roger Bacon in 1240 is credited with the invention of a contrivance

which enabled men to work under water. In Vegetius's De Re Militari, 1511, there is a cut or engraving representing a diver wearing a tight-fitting helmet attached to a long leathern pipe leading to the surface. In 1617 a water armor was invented, but in design proved impracticable. In 1679 an apparatus was invented in which air was forced down to the diver through a tube, and an apparatus approaching the design of the modern diving dress was invented in 1798, but it was not until 1830 that the modern dress, with a closed dress and helmet and employing compressed air, was devised by Augustus Siebe, and dresses today on this principle are employed throughout the world in harbor, dock, pier, breakwater and other similar works, in pearl and sponge fishing and in the salvage of wrecks. The compressors or air pumps generally in use are of three-cylinder direct-acting design and operated by hand. Where divers go to great depths or two or more divers are supplied from one pump, a two-cylinder double-acting pump is sometimes used; four-cylinder single-acting pumps and one-cylinder double-acting pumps are also in use. The compressors are actuated by power when the situation admits of its use; in this case the compressed air is first pumped into a receiver, thus insuring a reserve of air in case of breakdown in the compressors. The compressors are also arranged to operate either by power or hand. Gauges indicate the pressure being supplied to the diver as well as the depth of water. The so-called self-contained diving dress does away with the hose connections and pumps; the suit and helmet are of the ordinary pattern, but instead of receiving the air supply through a hose connection with the compressors, the diver is equipped with a steel cylinder containing oxygen at 120 atmospheres (about 1800 pounds per square inch), and vessels or chambers containing caustic soda or caustic potash. The helmet is connected to the chambers by tubes and the oxygen cylinder similarly connected to the chambers. The breath exhaled by the diver passes through a valve into the caustic soda, which absorbs the carbonic acid, and it is then again inhaled through another valve. This process of regeneration goes on automatically, the requisite amount of oxygen being restored to the breathed air in its passage through the chambers. This type of apparatus has been used for shallow-water work,

but divers prefer the air supply as pumped to them. An emergency dress, on the self-contained system for breathing, has been designed primarily as a life-saving apparatus for enabling men to escape from submarine boats. The greatest depth at which useful work has been performed by a diver is 182 feet in the recovery of treasure from a sunken vessel off Cape Finisterre. The sponge divers of the Mediterranean work at a maximum depth of 150 feet, and the pearl divers of Australia at a maximum of 120 feet, but diving operations connected with harbor or pier work are usually restricted to depths between 30 and 60 feet. The weighted tools used by divers vary but little from those in use on terra firma; pneumatic tools are employed where the situation admits of a suitable compressed air supply; the work of divers when performed by hand tools is slow and restricted and in consequence costly. The use of pneumatic tools, as in drilling, boring, chipping or like operations, when performed beneath the surface, increases the output of work to an extent that makes it comparable to results obtained ashore. In some recent trials and experiments, some naval officers have succeeded in reaching the unprecedented depth of 210 feet, and where they were under an air pressure of about 90 pounds to the square inch.

THE DIVING BELL.

Diving bells, according to tradition, were the invention of Roger Bacon, but probably the most trustworthy record is to be obtained in Kaspar Schott's *Technica Curiosa,* 1664. This account describes an experiment at Toledo in 1538 in the presence of the Emperor Charles V, when two Greeks descended into the water in a large ''kettle'' suspended by ropes with its mouth downward. The first practical diving bell was invented by Dr. Edmund Halley, Secretary of the Royal Society, which is described in the ''Philosophical Transactions'', 1717. This bell was of wood covered with lead to give it the sinking weight; in formation it was a truncated cone, 3 feet in diameter at the top, 5 feet at the bottom and 8 feet high; to admit light there was a lens at the top, also a tap to let out the vitiated air. Fresh compressed air was supplied to the bell by means of two lead-lined barrels; each barrel had a bung hole in the bottom and top heads;

to the upper hole was connected a leather hose tube so weighted that its lower end would always be below the bottom of the barrel and thus prevent the escape of air. The barrels were raised and lowered alternately; the leather hose, on the barrel on the bottom, was raised under and into the bell and thus permitted the discharge of air into the bell by the displacement of water entering the barrel from the lower bung. Halley remained in 50 to 60 feet of water for an hour and a half at a time without inconvenience. This type of bell was used in England at the time in repairing bridge foundations, but instead of replenishing the air supply in barrels, in 1778 the force pump or compressor was used to force air from above the surface to the bell. To John Smeaton is due the credit of designing the bell as in use today; that is, the square iron bell which sinks by its own weight. At present two types of bell are in use,—the ordinary bell of the Smeaton type and the air lock bell. Bells in which six men may work have a working chamber from 15 to 20 feet in length, 10 or 12 feet in width by 7 or 8 feet in height. The bells are lowered to position over the working face, or raised, by powerful steam cranes. Air is supplied from the compressors through flexible tubes to the bell. The bells are supported from barges or trestle or some like structure.

PNEUMATIC AIR-LOCK AND CAISSON.

The air-lock bell, which in principle and in construction is similar to the design of air-lock sinking caissons, as used ashore for foundations and for bridge pier foundations under water, comprises an iron or steel working chamber as in the diving bell, but with the addition of a shaft reaching through the roof of the bell to the surface. At the upper end of the shaft is an air-tight door and below it, at a distance of 7 or 8 feet, another air-tight door; the intermediate space between these doors is the lock. To enter the bell the upper door is entered, then closed and sealed; the air pressure in the lock is raised to the pressure in the bell, then the lower door may be opened and access gained to the bell by descending the shaft. To return to the surface or to remove excavated materials the action is reversed. The working chamber is lighted electrically and has telephonic communication with the surface. The diameter of the shafts is usually

about three feet. Pneumatic tools are now almost universally employed in work of this sort; they have many advantages over other forms of power-actuated tools. Steam, on account of the heat and vapor, is precluded from use, while on the other hand the escaping or exhaust air from pneumatic tools serves to maintain the air supply fresh and to replace the air vitiated through the respiration of the workmen.

PNEUMATIC TUNNEL SHIELDS.

The principle of the air-lock bell has its further employment in the construction of submarine tunnels. The tunnel shield for driving tunnels beneath rivers or harbors, was first employed by Brunel in driving a tunnel beneath the Thames. In 1818 Brunel patented a tunneling process, which included a shield and specified a surrounding wall of cast iron. In 1830 Lord Cochrane patented the use of compressed air for shaft sinking and tunneling in water-bearing strata. The shield and cast iron lining invented by Brunel and the compressed air of Cochrane have, with the aid of later inventors, removed the essential difficulties of subaqueous tunneling. Compressed air was first used in tunnel driving by Hersent, at Antwerp, in 1879, in a small drift with a cast iron lining; in the same year compressed air was used for the first time in an important work by D. C. Haskin, in the famous first Hudson River tunnel. This attempt was abandoned after a serious blow-out by which a large opening was blown through the soft silt and the inrush of water had caused serious loss of life. The accident had serious financial consequences which led to the temporary abandonment of the project, after the shaft had been advanced 360 feet. Ten years later this work was resumed and now forms part of the great underground and underwater transportation system of the tunnels and subways of New York.

LOCOMOTIVES.

Compressed air operated locomotives, because of their particular adaptability and advantages accruing from their use in underground workings and tunnels are becoming more generally employed as their mechanical efficiency is increased. About

1907 the tank pressures were about 750 pounds to the square inch with a working pressure reduced to 150 pounds; the locomotive could travel but 4000 yards before recharging of the tanks became necessary. In 1910 four-stage air compressors were built that could deliver pressures of 2250 pounds and the locomotives could store their tanks at about this pressure; the cylinders were compounded and a working pressure of 250 pounds or over was used in the high pressure cylinder. The locomotives could then travel 7000 yards without recharging, an improvement of 35 per cent over the practice of 1907, in air consumption. In 1912 another remarkable advance was made; compressors of five stages raised the pressures available to 3000 pounds and the locomotives were built with triple expansion engines and using an initial pressure of 400 pounds, with the result that the distance of travel was increased to 10,000 yards before recharging was necessary, the additional operating economy being 25 per cent. Modern mining locomotives weigh from 5 to 8 tons and are effective on grades up to four per cent. The time of charging approximates one and one-half minutes. In a seven-hour shift, in 5000-yard runs on good track, a capacity of 250 ton miles is maintained. This general outline of mining practice in compressed air locomotives is indicative of the tendency to very high pressures and the resulting economies in their employment. Stage compression up to 3750 pounds is employed in some cases.

RAILROAD AIR-BRAKES.

The employment of compressed air has solved the difficulties and manifold requirements of braking railway trains as exemplified in the Westinghouse Air Brake. The development of the air-brake has been one of the great engineering advances in modern times. In the Westinghouse automatic brake for steam railways, a main air reservoir is kept charged with compressed air at a pressure of 80 pounds to the square inch by means of a steam-actuated direct-acting air compressor; the compressor is bolted to the shell of the boiler in a vertical position. On electric railways, a motor-driven compressor is usually employed, but on trains where the run is short a compressed-air storage reservoir may be used. The brake is applied automatically under the vary-

ing conditions that may be brought about through accident, as the breaking of the continuity of the air transmission system. The application of the brakes is at all times subject to the control of the engine driver and may be applied with the degree of power or force requisite to meet the varying conditions of gradients, slowing up, or immediate or emergency stops. To each air-brake there is an independent air reservoir forming an extension on the brake cylinder; the triple valve, brake cylinder with its contained piston and spring and the air reservoir, constitute an independent and self-contained unit, which, upon accidental detachment from the rest of the train of the car carrying it, applies the brake automatically and brings the car to rest.

PNEUMATIC DESPATCH.

The pneumatic despatch or tube as a means of conveying small packages and mail has come into general use where conditions justify the adoption of the system. In London alone there are more than 40 miles of pneumatic despatch tubes; the pumps for this whole system consist of four 100 h.p. units. The system of tubes radiates from a common center, the length of the tubes varying from 300 to 10,000 feet. These tubes, in which the piston-like carriers travel, are formed of an outer casing of cast iron lined with lead and are usually from $2\frac{1}{4}$ inches to 3 inches in diameter. The 3-inch carriers will hold 75 message forms; the $2\frac{1}{4}$-inch, 25 forms; and an inch and one-half-carrier, 20 forms. In one direction the carriers are propelled by compressed air at a pressure of 10 pounds; they are drawn in the opposite direction by a vacuum of $6\frac{1}{2}$ pounds, which values give approximately the same speed. In addition to the radial system of distribution as employed in London there is the circuit system as adopted in Paris and many intermediate modifications.

PNEUMATIC GUN.

The pneumatic gun of Zalinski has demonstrated the advantages of compressed air as a means of discharging projectiles where the proper conditions for the operation of the gun obtain. Guns of large caliber were mounted at Sandy Hook, New York,

and at San Francisco, which are constructed on this principle. The Zalinski gun is of smooth bore, tube design, 15-inches bore and discharges a projectile containing 600 pounds of high explosive. Air at 1000 pounds is stored in tubes close to the gun, this tube being supplied from a primary reservoir where the pressure is maintained at 2000 pounds to the square inch. These guns have a range of 2400 yards and have developed great accuracy, greater than can be obtained with howitzers; another notable advantage is that through the operation of an automatic electrical device attached to the projectile, the shell may be exploded under water, thus in a manner replacing, in narrow channels, the submarine mine. This ability to explode the shell beneath the surface will provide, in a ship, a larger target, the increase being the immersed section of the vessel that would be in the line of fire. Rotation is given to the shell by the resistance or pressure of the atmosphere on curved or spiral vanes or wings on the projectile. The use of this type of gun, on ships, on account of its great length, so far has not proved of advantage.

TORPEDOES.

The Whitehead torpedo, a most potent factor in the present war, is driven by compressed air. This torpedo has a steel fish-shaped body which is propelled by two screws which run in opposite directions; this opposing rotation is to neutralize the tendency of the whole torpedo to revolve were but one propeller used. Four-cylinder engines of the Brotherhood type, working on compressed air, give the torpedo a speed of upwards of thirty miles an hour, with a range of accurate practice of more than 2000 yards. Air at 2000 pounds pressure is stored in steel chambers for use in the engines. The energy available from a given weight of compressed air is dependent upon the volume of air available at the working pressure of the engines; at a constant pressure this volume of air is proportionate to its absolute temperature. If then the air is stored cold and highly heated before delivery to the engines, the available energy from a given weight of air will be greatly increased. Upon discharging the torpedo the engines are put in motion, and means of highly heating the air being supplied to the engines become operative. For-

merly torpedoes were discharged from their tubes by compressed air, but the practice is now to employ a small charge of cordite or other explosive for this purpose.

SUBMARINES.

In submarine boats special arrangements are made to secure a cool and purified air. When traveling submerged the heated atmosphere of the engines and the exhaled air of the crew are drawn off through ventilators which pass it through various filtering, oxygenating and cooling devices, after which it is returned to the interior. By this means it is possible for the craft to remain under water for twenty-four hours without the crew experiencing inconvenience or difficulty in breathing. The electric accumulator compartments are hermetically sealed to prevent the escape of poisonous gases. Various safety appliances are fitted to prevent disablement of the vessel by the enemy or through accident. The water ballast tanks can be emptied of water and charged with compressed air very rapidly, there being a reservoir of air of ample capacity maintained constantly at high pressure for this purpose.*

TRANSMISSION OF POWER BY COMPRESSED AIR.

The first known instance of pneumatic power transmission was an installation devised by Denis Papin in the 17th century, where air was compressed by power derived from a water wheel and transmitted to a distance through tubes. About 1800 George Medhurst took out English patents for compressing air; he compressed and transmitted air which worked motors; he also constructed a pneumatic automobile. The first successful application of compressed air to the transmission of power was at the Mont Cenis tunnel in 1861. The form of compressor used was a system of water rams, several in succession, in which the water was the piston, compressing the air upward in a cylinder and forcing it out. The development from that time has been continuous until the development of our present day forms of highly efficient air compressors.

The large tunnels and metal mines and other forms of un-

* Scientific American Supplement, Sept. 5, 1914.

derground workings were naturally the first to utilize compressed air transmission as a means of power application in drilling, pumping, hoisting and the other operations connected with the particular requirements of each development. Several attempts at pneumatic railway propulsion have met with unsatisfactory results and development along these lines has apparently not made progress that would encourage the belief in its adoption as a system of railway propulsion.

CENTRALIZED POWER PLANTS.

In the operation of quarries and mines the large central compression plant has come to be accepted as the most effective and economical means of providing power for all the mechanism employed in operations of this nature. The markedly greater economy in the development and utilization of power from a central plant has reduced the costs of operation to such a degree that the economic advantages accruing are rapidly leading to the universal adoption of this system of power generation and distribution. These economies are brought about by the elimination of numerous small power units formerly scattered over works of this character, and doing away with the attendant labor, cartage and moving costs, the wasteful consumption of fuel inherent in small boiler units that are subject to varying demands, and to the advantage and improvement brought about by having a constant pressure of air always available at the most effective pressure. This permits of increased output with the same plant capacity, as the machines are in constant work. With a number of small boilers spread about in a steam-using plant, the uncertainties of pressure, labor, fuel supply and water are all multiplied proportionately to the number of separate units.

EFFICIENCY OF PNEUMATIC TRANSMISSION.

Generally, compressed air may be used in any form of rotary or reciprocating engine, motor or tool that may be operated by steam or gas. Air, in its marked advantages in transmission over steam, is increasingly being employed for power transmission; line loss through leakage in an air transmission line is an almost negligible factor; in a steam line of sufficient length the

condensation would render this form of power transmission impracticable.

The efficiency of a modern compressed air plant is very high, the loss in compressing air under the best conditions being less than 10 per cent. If the air, before use in the motors, drills, etc., is heated, a high power economy is obtained; as W. C. Unwin states, "For the amount of heat supplied the economy realized in the weight of air used is surprising. The reason for this is, the heat supplied to the air is used nearly five times as efficiently as an equal amount of heat employed in generating steam". There is in effect a hot-air engine using a medium much more effective than free air, in addition to a compressed air engine, which in combination makes the efficiency of the whole system extremely high.

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Mr. Selby Haar,‡ Mem. Am. Soc. M. E., opened the discussion by remarking that there should be some missionary work done to convince contractors of the necessity of keeping water out of the air. Mr. Haar.

Mr. W. L. Saunders (author) replying to Mr. Haar said that there had been several systems devised for the removal of water, some collecting the water before and some after compression. One method is by the use of intercoolers and another by the use of a drying system, consisting of cheese cloth baffles, which take up the moisture from the air passing through them. Mr. Saunders.

Mr. L. Duncan,* Mem. Am. Soc. M. E., stated that air always leaves the compressor at a higher temperature than the atmosphere and upon cooling a loss of volume takes place, which is an important loss. Mr. Duncan.

Referring to intermediate pressures between 8 and 20 pounds per sq. in., he said there were two types of blowing engines used—reciprocating and turbo-compressors. Of these, the turbo-blower gives the highest efficiency in the long run. This is due to the fact that it has a lower number of wearing parts.

Prof. J. C. Breinl,† Mem. Am. Inst. M. E., replying to question by Mr. Lindsay Duncan, stated that the heating of the air is a natural effect of the compression and in reciprocating compressors it is greater than in turbo-blowers, due to the continuous cooling in the latter type. In spite of this, the overall efficiency, based on isothermal compression tested by nozzle measurement, shows a figure of about 76% for reciprocating compressors when fitted with properly designed valves, such as the Ingersoll-Roegler, as against 66% for the highly developed turbo-blower. The valves of the above-mentioned type become tighter with continuous use, and therefore if a modern compressor of this type is also fitted with a construction to support the piston and prevent wear at that point, and is fitted with metallic packing, there is no reason why such a machine should decrease in efficiency due to wear any more than the best turbo-blower, as the latter also falls off in efficiency as the result of the inevitable dust which gets into the machine even when the intake is fitted with a well-designed air filter. Prof. Breinl.

Regarding the high speed of the turbo-blower, the drive can be either direct or geared to a steam turbine up to speeds as high as 6000 r.p.m., and in the case of an electric motor, up to 3600 r.p.m. In general, it may be said that for smaller units and higher air pressures, the reciprocating compressor is to be preferred, and for larger units and lower air pressures, up to 100 lbs., the turbo-blower has the preference. At any rate, the choice is one wholly dependent upon the cost of investment and of operation; and taking these into consideration, it can be said that, for lower pressures and from about 300 horsepower upwards, and higher pressures up to 100 lbs. and from 800 to 1000 horsepower upwards, the

‡ New York, N. Y.

* Mech. Engr., Nev. Consol. Copper Co., McGill, Nev.

† Professor of Austrian Mining University, Pribram, Austria.

Prof. Breinl. turbo-blower has the advantage; but these limitations cannot be fixed absolutely, as they will depend upon operating conditions. In the case of units smaller than the above sizes, the modern reciprocating compressor gives in every way the best results from an economical and operating standpoint.

Mr. McWilliams. **Mr. McWilliams** said that compressed air had taken the place of electricity in the automatic double block systems of the New York subway.

Paper No. 129

SAFETY ENGINEERING.

By

FREDERICK REMSEN HUTTON, Sc. D.
Past-President of the American Society of Mechanical Engineers and Honorary Secretary; Vice-President of the American Museum of Safety
New York, N. Y., U. S. A.

Safety may be defined as the condition of being protected from assault or untoward circumstance. Industrial Safety, with which this discussion concerns itself, is such a condition of protection in the surroundings of the wage-earner and in the purview of the factory and the shop of productive industry.

Safety is a broader concept than immunity, for the latter means a protection from a harm when a specific attack is made: while Safety is the fact of protection both when the attack is made and at all other times and from all other forms of assault. Immunity from typhoid does not mean safety from railway accident, or even from tuberculosis or pneumonia.

There will be two kinds of Safety. The attack will be upon the body of the worker, upon its softer tissues or its stronger bony structure; or it will be on the effectiveness of its physiological functions. In the first case, there is an impact of a mechanical force too great for the resisting power of flesh and bone to withstand, and under it the member or the body is crushed or mangled, and the body is maimed. In the other case, the physiological processes of repair or replacement of wastes in the body are disarranged by some slow (or rapid) invasion of poisonous matter absorbed in respiration, or through the skin, or in the food. There will therefore be a Dynamic Safety, and a Physiological Safety. This latter may be called Industrial Hygiene, or Sanitation, and is rather in the scope of the medical man and technological expert. For this reason and for lack of space and time, it will be only thus

summarily referred to. The dynamical field is that of the mechanical engineer and will be the thesis of this paper.

A moment's analysis will show that in securing safety in the shop and factory against mechanical injury from the forces at work, there are two directions along which safety may be sought. An illustration will make this more obvious. A highway, for example, may be made "safe" by eliminating the bandit and the highwayman who have infested it; or, it may be made safe by providing adequate escorts and organizing caravans which shall be strong enough to repel attacks. So in industry, safety may be sought and secured by the design of the machine, whereby danger shall not lurk for the operator; or safeguards or safety devices may be applied to it, which shall make it difficult for the tissues of the body or the clothes of the operator to become entangled in the moving masses. It should be said at once that it is much better engineering to avoid raising a question or meeting a problem, than to create ingenious and costly solutions to questions or problems which have been made necessary because the engineer was not shrewd enough to avoid them altogether. In other words, basal design which raises no dangers is better than prevention of accident by safety appliances at points of danger.

Furthermore, safety in the shop or the industrial atmosphere is also, like residence in certain fortunate cities, a state of mind. It must be secured not only mechanically, but by attention to administrative detail. Some men—in fact most men—are prone to resent the pressure for safety by appliance, and to feed their self-esteem, both when alone and in the presence of onlookers, by taking risks. This is one of the objections to the presence of visitors at the factory. The workman's manner says: "This would be dangerous to the unskilled or inexperienced, but to the old hand, or to the gifted such as I, the demon of accident is too stupid or too slow to catch a live one like me. I may take risks intrepidly, but none of you onlookers should". It is to meet the heedless and careless in this class, that the slogan of "Safety First" has the greatest usefulness, and that education may well exert itself to convince the reckless that a man's dependents are often the worst sufferers from an accident, and the community bears much of the loss from an indus-

trial death. Some men must be spurred to safety in their own despite.

Again, it may be well in this foreword to answer the question: Why spend money and effort to secure safety in the industries? The answer is threefold. In the first place, as a matter of Christian altruism, the able and trained engineer has a duty to prevent the physical pain and suffering of the victim of an industrial accident. There is a real sense in which he cannot avoid being his brother's keeper. In the second place, there is the burden of bereavement and sorrow and of mental agony and spiritual distress and disappointment to be borne by the family and dependents of the man injured. These are burdens which no insurance or money compensation can pretend to reach or to remove: the most that these can do is to lighten. But the third consideration is the economic loss from an industrial accident. The nations of Europe, and Germany in particular, saw this before we in America woke up to it. The broad principle of economic working of a tool or machine is that it should be continuously at work, earning by its product the interest on its cost, and helping to pay overhead charges. Any cessation of productivity, or tool-idleness, is an invasion of economy. But an accident retards or stops productivity: first, by the disablement of the skilled operator himself; second, by the nervous shock to all who witnessed the accident and who ran to help; third, by the deranged productivity in the whole department where it happened; fourth, the loss of time to train a new operator to the skill and speed of the old one; fifth, the loss from defective work in this last process. Then, the direct losses in the cost of compensation and insurance, and the indirect costs of the ambulance and hospital expenses, borne through the community as a whole, as well as premature pensions and losses of schooling for those who are forced into wage-earning, before their time, to take care of dependents. Hence, there can be no argument except on the one side.

Again, it may be useful, in further analysis, to note that industrial safety, or the prevention of accidents, presents itself under three heads. The first accident is one which happens to the tool or machine and disables it, but does not harm the ope-

rator. The second is the accident to the operator, but which does not harm the machine; the third is a combination of the two foregoing, in which both tool and operator are endangered, and perhaps the innocent bystander. It is easy to extend this third class to include the passenger or user of public service apparatus. On the railway and on the water and on the highway, the machine and its crew, taken together, are the machine, and the general or the traveling public are additional persons injured when the accident happens.

Finally, a distinction should be made between making a machine safe, and making it "fool-proof". A fool-proof safety equipment would mean one in which the ignorant toddling child or the curious finger of the idiot could not find access to the zone of danger in operation. The best thinkers hold that a certain alertness of mind in the presence of possible danger is favorable to safety of body, as well as to rapid and economic production. For this reason, safety engineering should not be overdone. Moreover, safety designing must not antagonize speed of production, or invade the wage-earning capacity of the operator beyond the point at which his interests begin to suffer. When this point is reached, human nature being ambitious and self-seeking, the safety apparatus will be unpopular, and presently cast aside.

A distinction which must be made in any discussion of safety will again limit the field of treatment in this paper, between the types of safety attainable within confined spaces and with stationary tools, and that to be planned for in the open air industries, such as the railway, the quarry, the building plant, the mine and the navigable body of water.

Recapitulating within these limits set, a broad survey of Safety Engineering reveals four great divisions of the subject:

Division I. Accidents and safety apparatus to prevent them, originating from the sudden injury to the body from the motor forces in industry.

Division II. Gradual disability and loss of wage-earning capacity from slow-working physiological causes, resulting in occupational disease.

Division III. General. Combinations of the above two.

Division IV. Betterment. Methods for increasing the

wage-earning capacity of the human unit, by improving his physical condition and mental surroundings.

Group IV is for the philanthropist, the Christian works-manager and the altruist in general. Group II is for the physiologist and the medical expert. The mechanical engineer designer and works-manager has Group I as his special field of activity.

The foregoing analysis has made almost unavoidable the philosophy and sequence of the detailed discussion next in order. It should begin with the prime mover as a source of possible destructive energy; follow through the methods of transmitting that power, by shafting, gears, belts, piping and wire; discuss the dangers met in internal transportation by elevator, shop-railway and crane; and finally treat of the dangers at the working zone of the tools or machines. If the treatment were to be at all complete, the tools or machines would be those of the wood-working shop, the machine-shop properly so-called, the foundry, the chemical establishment, and the miscellaneous productive or manufacturing installation. Accidents are also due to exposing the body to the action of gravitation and injuries from its fall or the fall of heavy masses on it. There are also the problems of collective safety, where numbers are in one place, and the dangers from fire and smoke and panic are to be guarded against. It will therefore be plain that to keep treatment within the practical limits set by wisdom and the proprieties of the case, some of the topics glanced at above must be arbitrarily passed by, and attention directed to a selected remainder: and that the discussion offered cannot be exhaustive in any case.

I. SAFEGUARDING THE SOURCE OF POWER.

To assume the general case, consider a horizontal Corliss engine. It will have dangers from the valve-gear, the cross-head, the crank and connecting-rod, the fly-wheel and the revolving shaft. An arm or a hand or clothes or a foot may be entangled, or a slip or a fall may bring a burnable tissue against hot metal. Safety is therefore to be secured by surrounding the whole danger zone by a "keep-out" fence. The

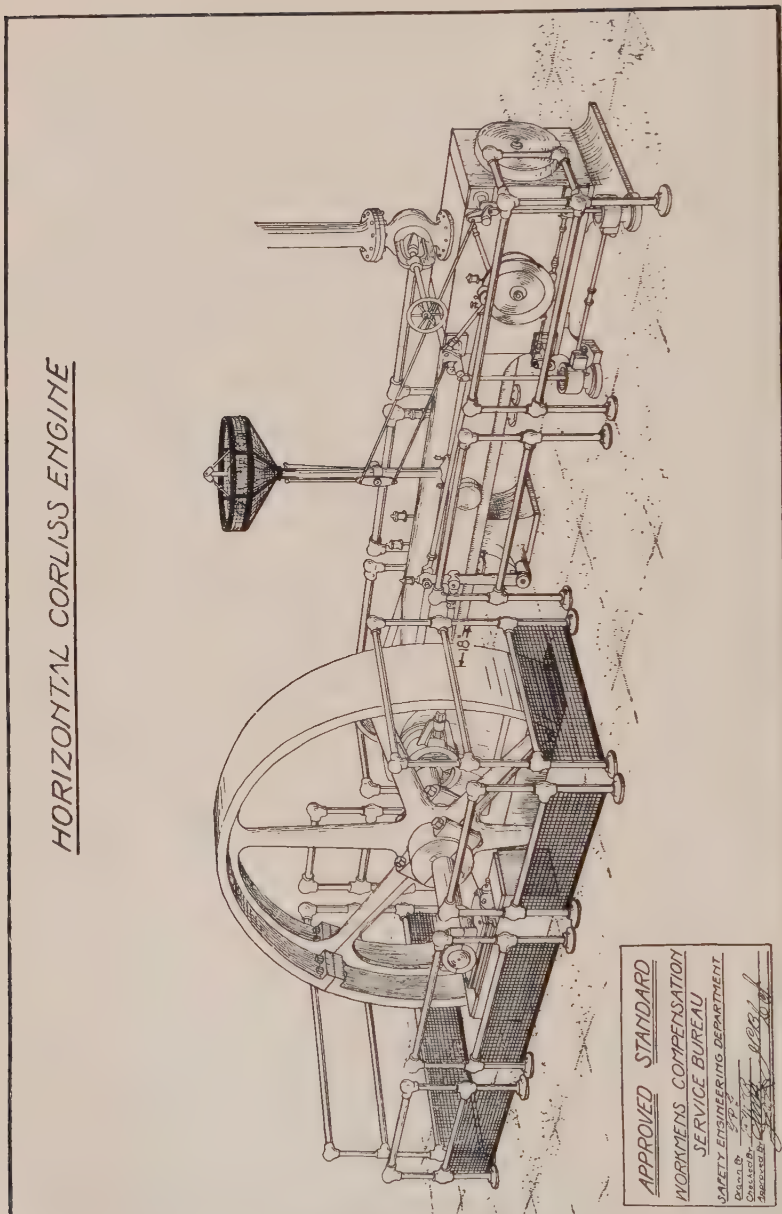
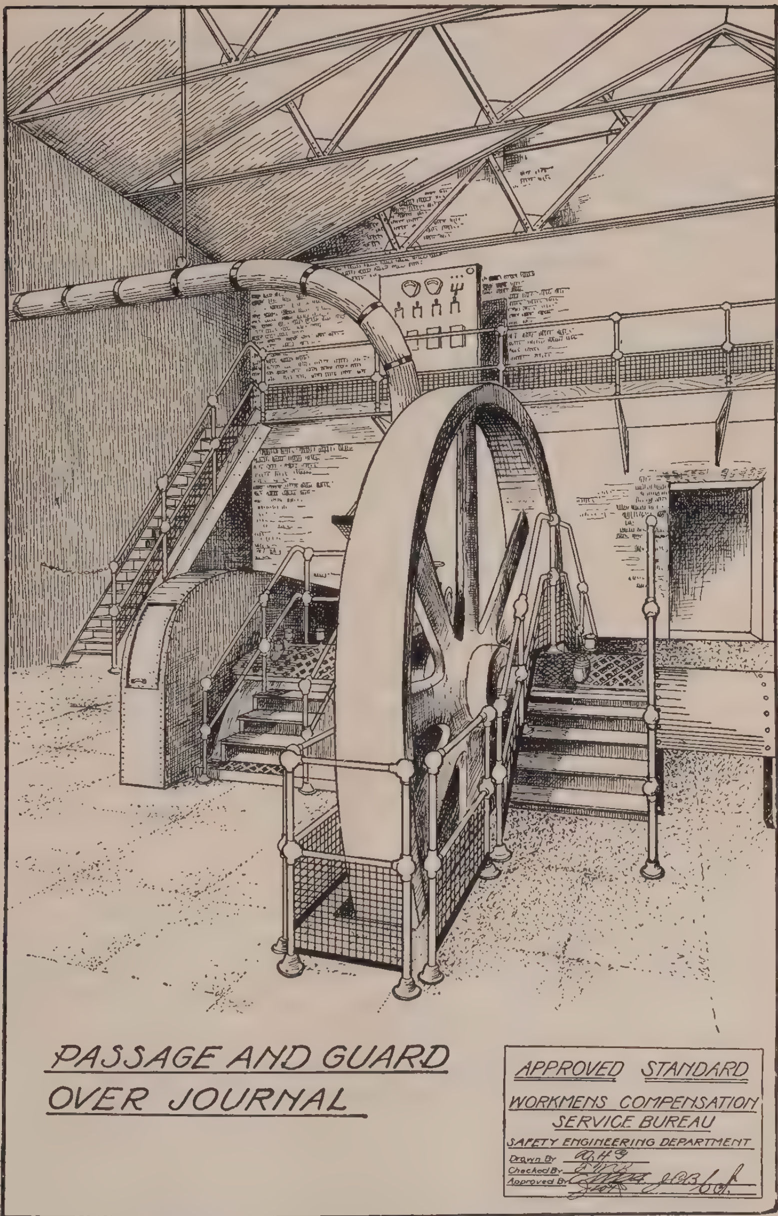

HORIZONTAL CORLISS ENGINE
APPROVED STANDARD
WORKMEN'S COMPENSATION
SERVICE BUREAU
SAFETY ENGINEERING DEPARTMENT
Drawn By
Checked By
Approved By

Fig. 1.


PASSAGE AND GUARD
OVER JOURNAL
APPROVED STANDARD
WORKMENS COMPENSATION
SERVICE BUREAU
SAFETY ENGINEERING DEPARTMENT
Drawn By
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Approved By

Fig. 2.

illustration chosen in Fig. 1 shows a pipe-rail design, which is usually the best looking, with a bank-lattice netting in combination. The path of the governor balls is also isolated. The bank lattice serves to prevent a slip into the wheel pit, and to keep any rolling object from falling against the wheel or its spokes. Panels of bank lattice may be used instead of the pipe-posts and rails, and the toe-guard may be of wood. Alternative safety guarding for the reciprocating parts is shown in the second illustration, where a sheet-steel covering envelopes the crank and is led back nearly to the cylinder. This has a latticed opening in front of the crank for inspection and for coolness, and sliding panels give access to the ends of the connecting-rod, that the operator may feel the metal from time to time to detect overheating.

This illustration shows, also, a fine safeguard for large engines, by having the main bearings made the safe means of crossing the shaft. The steps and railings make the oiling of these critical points far less dangerous. The cut shows also the use of toe-guards on the gallery face; this toe-guard prevents one slipping through and also prevents the rolling of objects down on to the moving parts below.

If the source of danger is an electric motor for a section of the plant, it can be made both safe and fool-proof as shown in the third sketch. The lattice cage can be opened only by unlocking the panel, and the belt is also made harmless. Its cage can lead the belt at any angle. The operating switch should be outside the cage in all cases.

Engine Stops.

Complete safety at the origin of power and motion calls for engine safety-stops. These are of two diverse kinds, and they may be used together or independent of each other. One kind is to prevent a racing of the engine in case of some disarrangement or failure of the governing apparatus, or a release of the normal load, so that it tends to speed-up to a dangerous rate. A racing engine may rupture its fly-wheel; or if connected mechanically to operative machines, the overspeeding may do great harm all through the plant. Such anti-racing stops are of many types, but, in the main, they depend on having a weight, of sufficient magnitude, whose fall shall shut the throt-

tle, and which shall normally be held up and only released to shut the valve in case of need. The detent, which holds the weight from falling, may be released electrically from distant points, or it may be connected mechanically and directly to the governing mechanism, and be released when the latter fails to act, or it may be released by hand in emergency. The other type shuts down the main engine directly from a distant point, in case of accident or emergency, and does this quicker than it could be done by any signal to the engine room. The common principle has been foreshadowed above, where a weight in its descent can close the throttle, such weight being held up by an electrically operated detent. If the detent is released when the accident occurs, the engine stops in a relatively few seconds. The most reliable stops operate on a closed circuit, so that an opening of the circuit at any push-button in any department releases the detent. If the circuit is out of order, the weight falls. To keep these stop systems alert and always ready, they should be used at noon and night, from the distant switches in succession, day by day, so that the system may be continuously operative and not fail in exigency of need. Sections of the plant should also be isolable by mechanical clutches or electric switches, to this same end.

II. SAFEGUARDING THE TRANSMISSION OF POWER AND MOTION.

Transmission of power and motion from the prime-mover to the machinery and tools or processes will be by shafting and belting, with some gears; or, by pipe or wire. The shaft and belt system is by far the most dangerous. Where the belt comes up through the floor (Fig. 4), a lattice-panel safety is the most serviceable, and it should have a height sufficient to eliminate the risk of a woman's hair being entrained in the windage or the electric zone of the moving belt. When the belts lie somewhat horizontally and overhead, a guard netting under the lower bight should safeguard against an injury if the belt breaks, and will keep hair from being entangled.

Shafting will be, usually, overhead, to keep belts out of the way and to leave the floor free for tools and transportation.

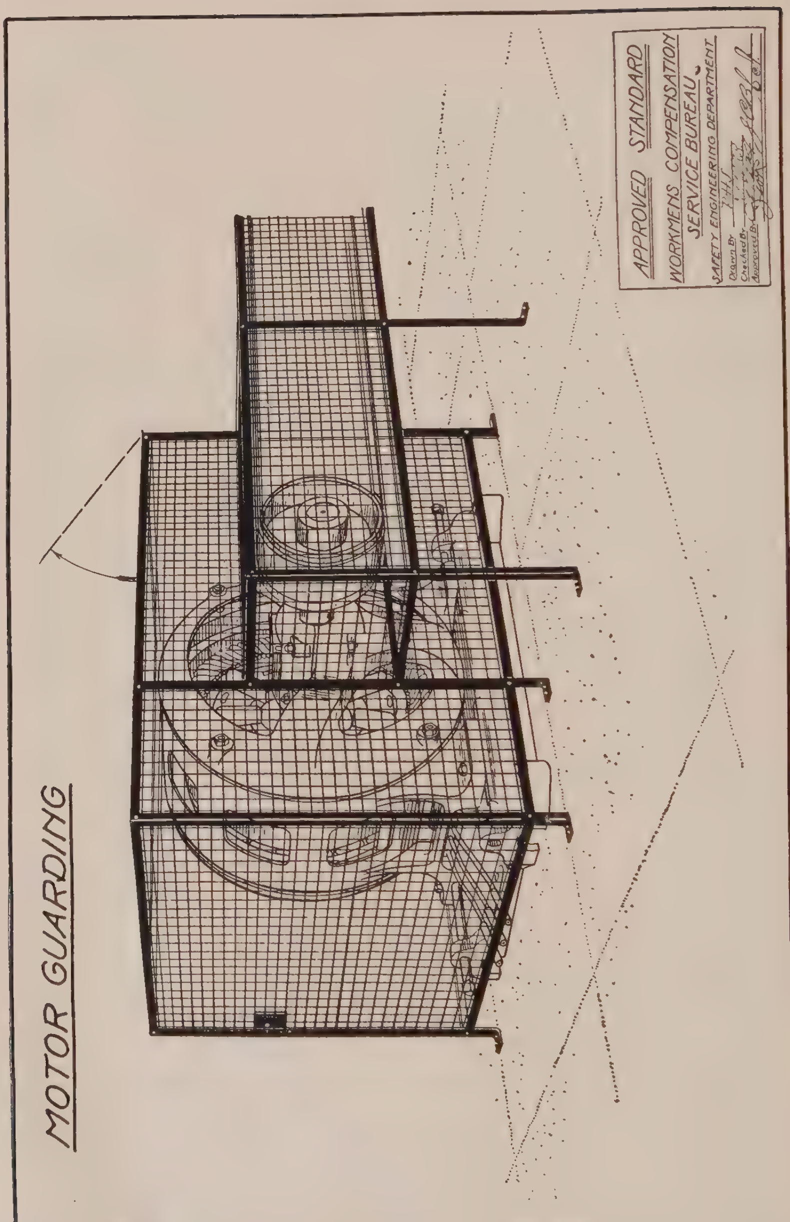
MOTOR GUARDING
APPROVED STANDARD
WORKMENS COMPENSATION
SERVICE BUREAU
SAFETY ENGINEERING DEPARTMENT
Drawn By
Checked By
Approved By

Fig. 3.

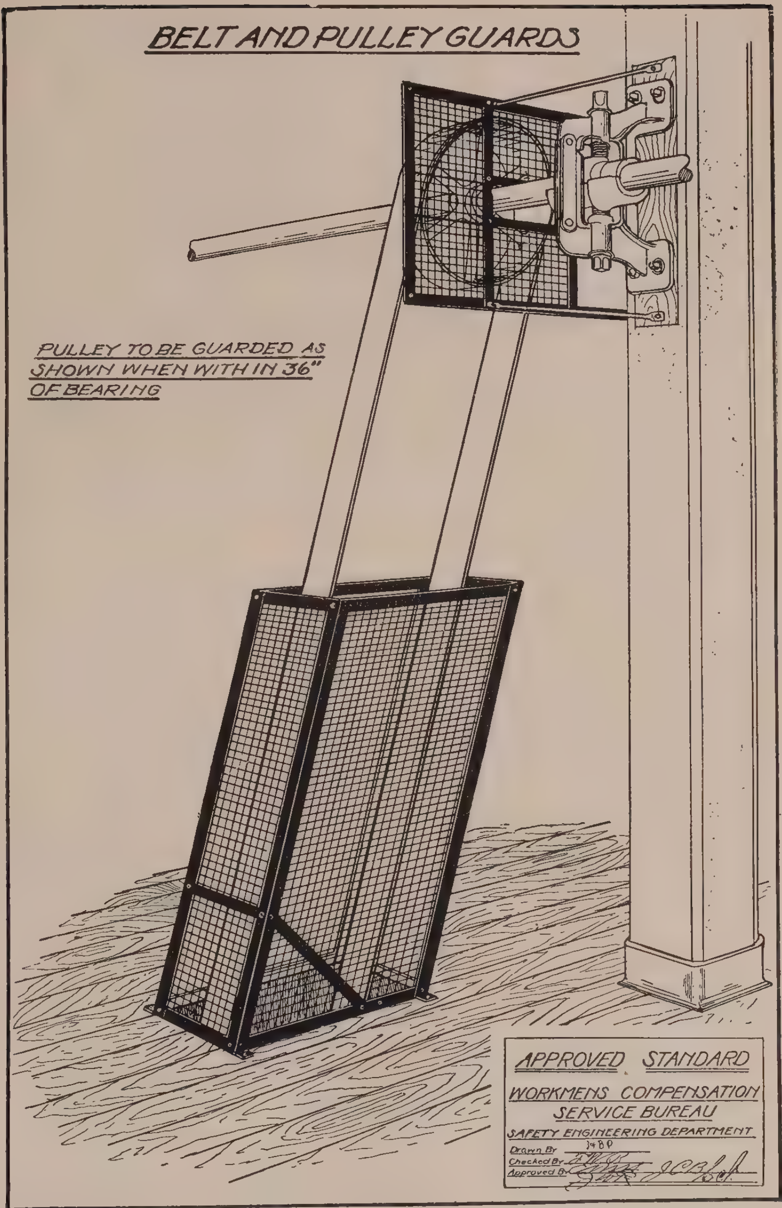
BELT AND PULLEY GUARDS
PULLEY TO BE GUARDED AS SHOWN WHEN WITH IN 36" OF BEARING
APPROVED STANDARD
WORKMENS COMPENSATION SERVICE BUREAU
SAFETY ENGINEERING DEPARTMENT
Drawn By
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Fig. 4.

Hence, its dangers are to the oiler who mounts, by a ladder, to the shaft level and may have an arm or clothes caught in the revolving units, and the dangers to those below, should the shaft be dragged down. The oiler's danger is minimized by the mesh screen, shown in the fourth cut, and by suppressing projecting set-screws on pulley hubs and projecting bolt-heads on flange couplings. The use of so-called "hollow" set-screws and the recessing of the flange faces to take the bolt-heads and nuts are means to avoid these troubles. Some designers have covered the entire shaft with a hollow sleeve, which turns with the shaft when it meets no resistance. A man's arm or body against the loose sleeve will arrest its motion, while the shaft revolves harmlessly underneath.

Accidents from a slippage of the ladder on which the oiler stands have been lessened by fitting the top of the ladder with a hook on each upright; and by equipping the feet with pads which have a full bearing on the floor, and which may have a non-slip material on the contact faces.

For the run of the main line of shafting, with countershafts connected thereto, the pulleys should not be so near the hanger or bearing on either that a strong, new belt running off the pulley would jam in the space between hub and bearing and pull down the shaft by breaking or stripping the holding bolts. The clearance space at the side of the pulleys should be greater than the widest belt or pulley face.

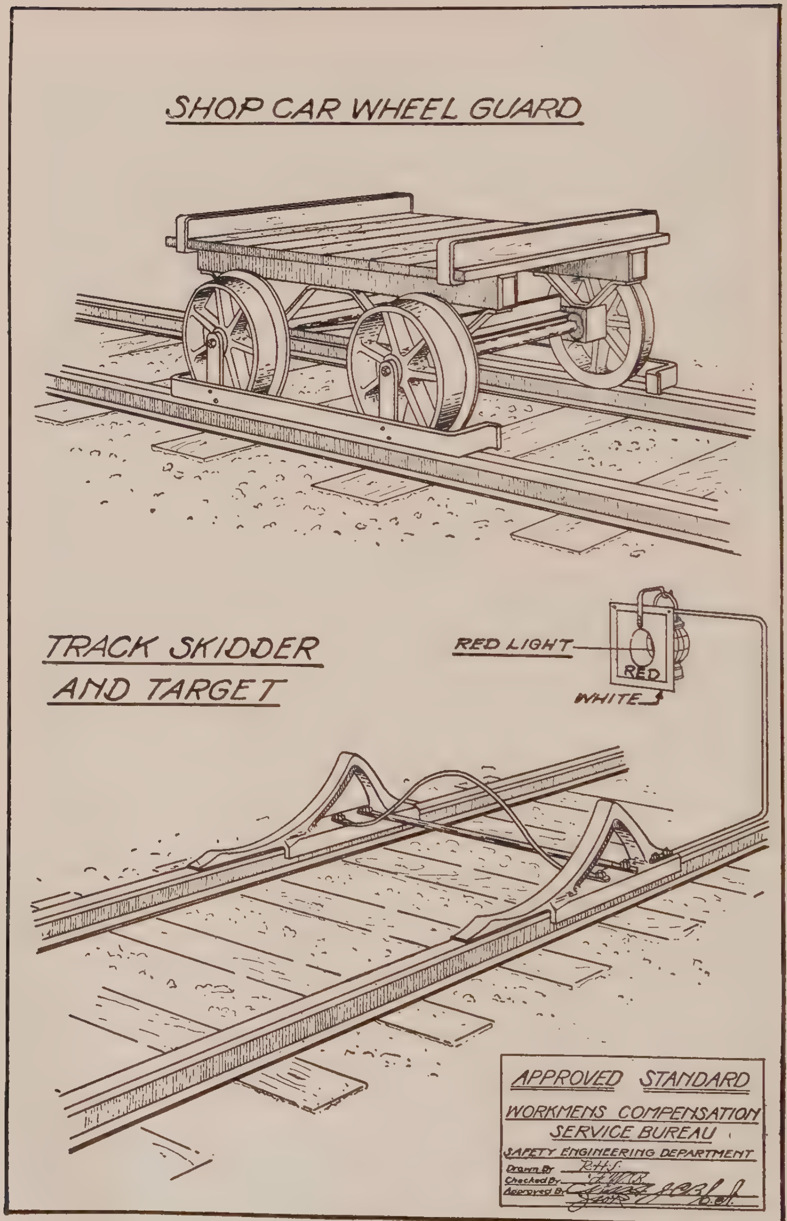
Chain drives, operated by sprocket-wheels, are a most dangerous transmission when unprotected. Clothing caught where the chain and wheel come together can only be released by tearing. Both the sprockets and the chains should be lattice guarded. Toothed gears in mesh, in transmission of power and motion, are a most prolific source of accident to the hand and fingers. The danger zone is those parts of the toothed circumference of both wheels which are approaching their point of contact, and the crushing of the hand or fingers between the teeth means amputation or loss of use. The faces which approach one another and the sides or bases of the cylinders or cones should be guarded, either with sheet steel or lattice. The lattice is cleaner, allows lubrication through the mesh and permits air circulation. The guards should be removable, for ac-

cess to clean the gears, but not so easily put out of place as to defeat their purpose.

Power is transmitted also by the electric wire and by piping carrying pressure. The main leads should have line switches, for safety, dividing the plant into sections, as has been urged for the shaft system by the use of clutches. By opening such switches, the sections below them are cut off and become dead. Such a switch should be capable of being padlocked open, so that a worker below it would be in no danger of having current turned on until he is ready. Piping may also, wisely, be in sections and have quick-motion valves, so that in accident or in repair the pressure may be shut off; and the valve wheel should also be lockable and the key held by the man who would be endangered if the valve were opened through carelessness or misunderstanding.

III. SAFEGUARDING INTERNAL TRANSPORTATION.

The traveling crane has been in use for fifty years as a means for picking up heavy masses at one point and depositing them in another. It assembles big engines and puts heavy work on planer bed or lathe. There are five classes of danger to which it leads. The first is to its own structure, from over-running its track and from derailment. This is met by safety stops on its rails, and by so designing these stops that the current driving the crane is cut off when the crane hits the stops. The second is from over-hoisting; this is met in the same way as in over-running, by making the excessive lift cut off the actuating current. The third is the danger to men below from the falling of any parts of the crane structure, such as keys or bolts. This is met by having a mesh or lattice netting under the entire structure to catch such missiles. (See Fig. 11.) The fourth is the accident from a fall of the load from its slings by slipping, or by a failure of the hoisting cable or chain or hook; and the last is the risk to the overhead operator in going to his place. Ceaseless care and unremitting inspection and skill in slinging reduce the former; and the construction of railed gangways should prevent the last. It should be a shop rule never to walk or stop under a load suspended from a crane; and blocking


SHOP CAR WHEEL GUARD
TRACK SKIDDER
AND TARGET
RED LIGHT
RED
WHITE
APPROVED STANDARD
WORKMENS COMPENSATION
SERVICE BUREAU
SAFETY ENGINEERING DEPARTMENT
Drawn By R.H.S.
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Approved By

Fig. 5.

should always be laid under a piece of work so suspended when a man is to work where he would be crushed if something gave way or the tackle overhauled.

When transportation from shop to shop is by buggies or cars on a railway on the floors, the time of transit from car to crane is one of danger. If the lift of the crane is not vertical but has a direction in which the car is free to roll, the feet of the men around the car are in great jeopardy. A toe-board, such as is shown in the cut, is quite worth while.

The elevator, as a means of internal transport, is a railway, with a car running on a track, albeit a vertical one, and is an obvious source of danger. It appears in two general classes for freight purposes: In one, the car moves in a well or in a tower reserved for it; in the other, it moves through hatchways, or openings in the floors, which are not isolated, but are located where convenient. Neither space nor the intended scope of this paper permits any full treatment of the passenger elevator for hotels or offices or the department store; but, in general, the dangers arise from a possible fall of the platform or cage with people on it; the catching of the human body between the moving platform and the fixed structure of the floors; and the fall of the body into or down through the open hatchway. The danger is greater with a hatchway in an open floor than with the elevator in a well; since a man can approach the opening from all sides in the former case, and only from the front in the latter; but the principle of safeguarding will be the same in both cases. Skilled insurance inspection of cables and the progressive grip on the guides of modern elevator "safeties" and the use of the plunger type of elevator will diminish the cage or platform accident, and improved gating must be looked to for the reduction of hatchway dangers. With elevator wells, the principle of interlocking the gate with the starting mechanism can be applied so that the car cannot be started from any floor until the gate is closed; and the gate cannot be opened unless the platform is at the floor level and closes the well opening. Such interlocking can also prevent a man from being caught between the fixed floor and the moving platform, because the gate must be completely shut before the car is started from the floor level, and the car must be

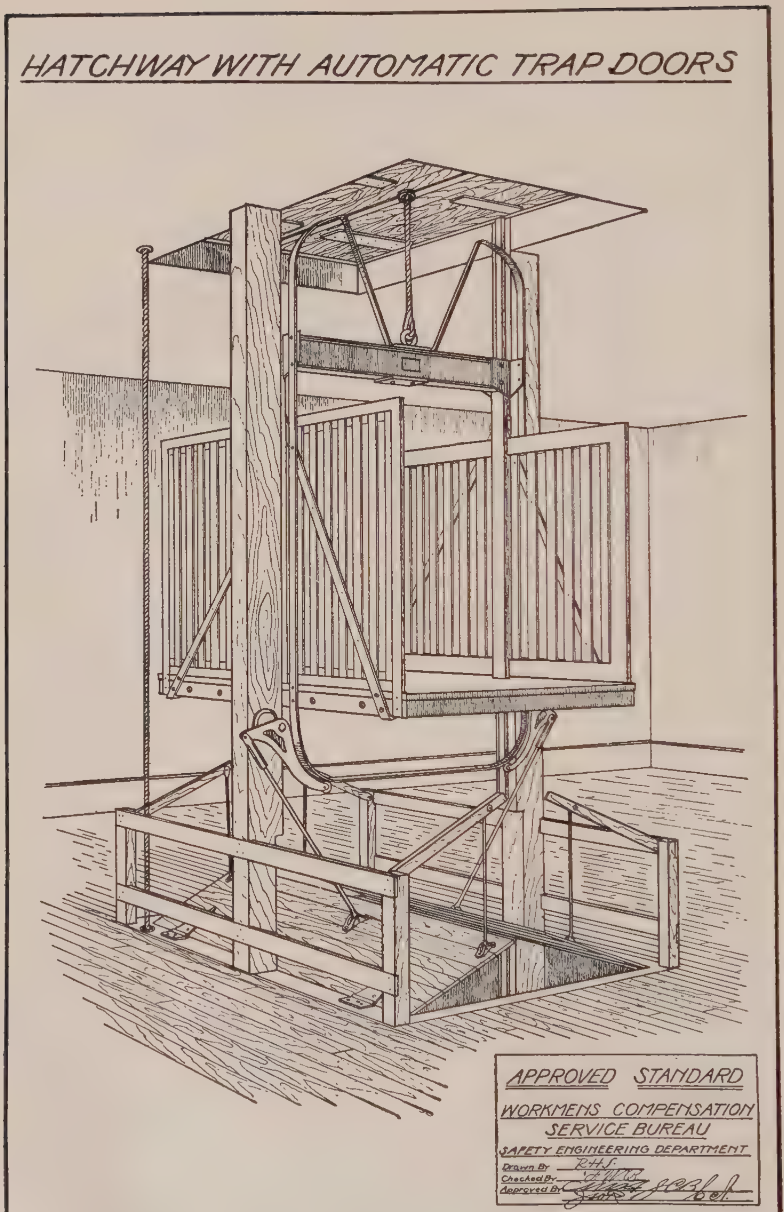
HATCHWAY WITH AUTOMATIC TRAP DOORS
APPROVED STANDARD
WORKMENS COMPENSATION SERVICE BUREAU
SAFETY ENGINEERING DEPARTMENT
Drawn By R.H.S.
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Fig. 6.

at rest at such level, before the gate can be opened. This interlocking can best be secured mechanically, rather than to depend on electric devices. There are several effective designs for this purpose. Adequate lighting at the hatchways and wells will also greatly lessen all types of accident at these points. The cut selected shows how the floor type of hatch can be safeguarded.

IV. SAFEGUARDING AT THE INDIVIDUAL TOOL.

The limits of time and a wise conservatism as to the length of a paper make themselves felt as the discussion approaches this division. It is as wide and as diversified as the field of industry, and that of the skilled activity of the operative of power-driven tools and machines. Hence, for brevity, only four typical sources of danger and the remedies therefor will be examined, leaving it to skilled ingenuity to apply basal principles to the manifold varieties of the problem and their needs. The metal punching or drawing press, the saws of the woodworker, the metal-working lathe, and the emery wheel will be so selected.

There will always be the movable ram, or plunger, and the fixed die in the punching or metal-drawing press, and the metal to be formed must be fed between them in order that the mechanical force may be exerted to shape it up. If this stock is fed by hand to the die and ram, the operator's hand will be approaching the danger area as the ram starts down. Any distraction or fatigue or other cause which throws the hand out of synchronism with the rhythm of the continuously reciprocating ram will catch and lacerate the tissues so entangled. Mechanical feed-motions or mechanisms are first remedies, so that hands and fingers need not enter the impact areas; but these are not always applicable. A second remedy is an arm which sweeps across the die-face in advance of the descending ram and connected thereto, whereby a hand in danger is thrust away from the path of the force. (Fig. 7.) These are effective for the continuous-motion presses. For those of larger type, where the motion of the ram results from a clutch engagement of the ram-shaft at the will of the operator, safeties may take the form of curtains

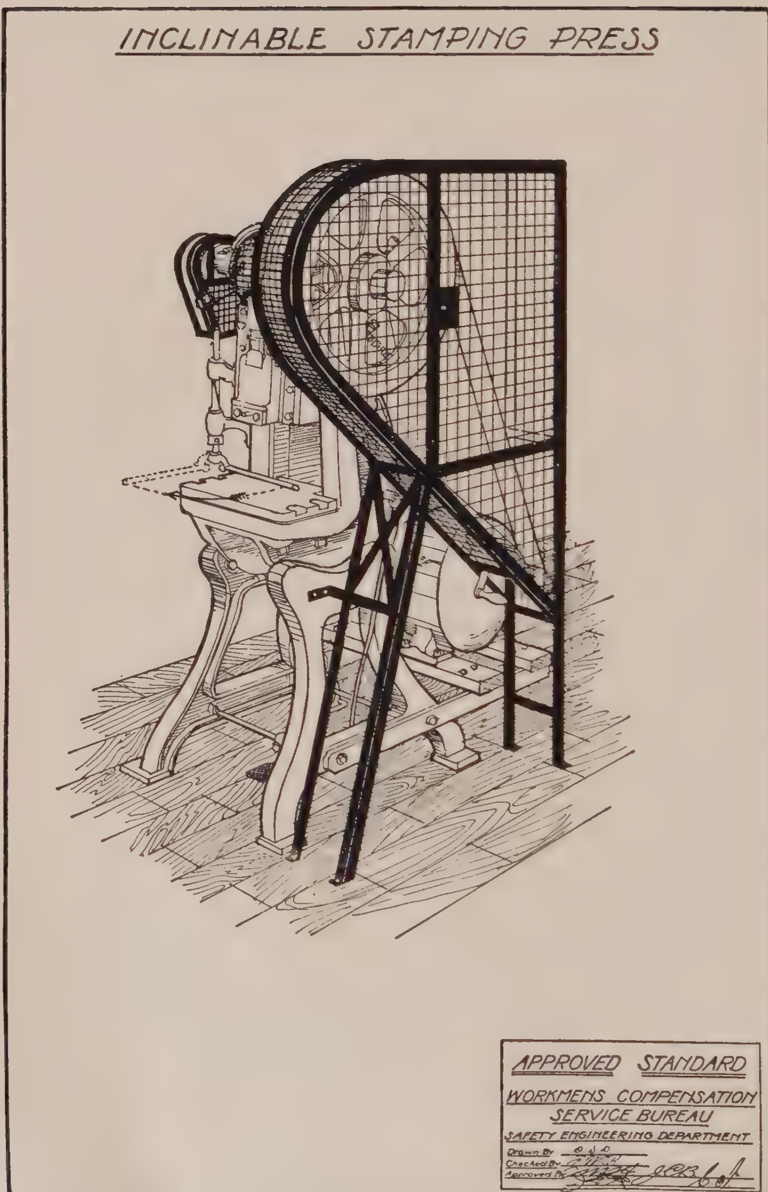
INCLINABLE STAMPING PRESS
APPROVED STANDARD
WORKMENS COMPENSATION
SERVICE BUREAU
SAFETY ENGINEERING DEPARTMENT
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Fig. 7.

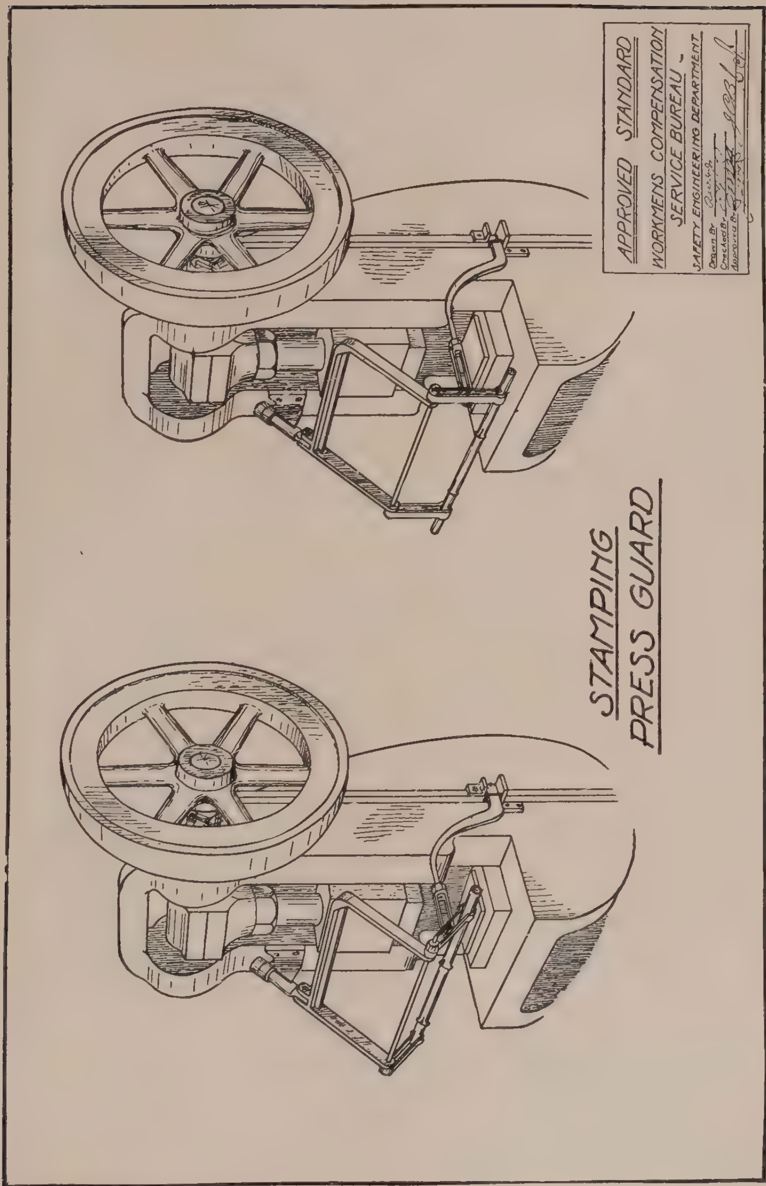
STAMPING
PRESS GUARD
APPROVED STANDARD
WORKMENS COMPENSATION
SERVICE BUREAU -
SAFETY ENGINEERING DEPARTMENT
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Fig. 8.

or cages of linked bars, which must be allowed to fall to place before the clutch can be engaged. An arm under the bottom edge of such a portcullis and in danger of harm prevents the stroke from happening at all; or, the portcullis may be reduced to a bar-frame (Fig. 8) ; or, the clutch movement may be made to require concurrent action of both hands of the operator, leaving neither of them in danger when the stroke occurs. An ingenious schemer proposed an electrically insulated plate around the die, which should be charged, through an interlocked switch with a high-tensity low-quantity electric current before the ram started down. A sharp shock on the hand resting on the plate would result in an instantaneous withdrawal of it before the ram could reach it.

It is the pitiless high speed of the cutting-edge of wood-working tools which leads to their danger. The teeth of the circular saw, for example, disappear in a halo around its visible disk, and yet the danger is in the halo ring. Band-saws moving at a high rate of speed are flexed over their carrying wheels, and are twisted, in sawing curves, where the blade enters the wood. They are liable to part under stress, and the freed ends to cut the operator in face or head. Circular saws may also convert the cut strip into a javelin as it is released or splits at the end of a ripping cut, and hurl the weapon against any one in its path of flight at high velocity. Band-saw safety is best secured by boxing the carrying wheels; and safety for circular saws by hooding them, leaving exposed only the small sector at which the work is to be done. Circular-saw hoods must usually be supported and adjusted from above the table, so as to leave the latter free in all directions, to receive stock lengthwise, crosswise, and at angles.

For the wood-working surfacers, buzz-planers and jointers, and for the shaper or friezing machine, there are cutting knives held in a "head" and the hand may be brought very near to the cutting edges in holding the stock and presenting it to the cutters. A well-designed form of cutter-head will greatly reduce danger, and top-guards and cages, guides and self-feeding attachments are the appliances suggested.

The lathe is taken as a type of the metal-working tool driven by power with whose mechanism the operator has to

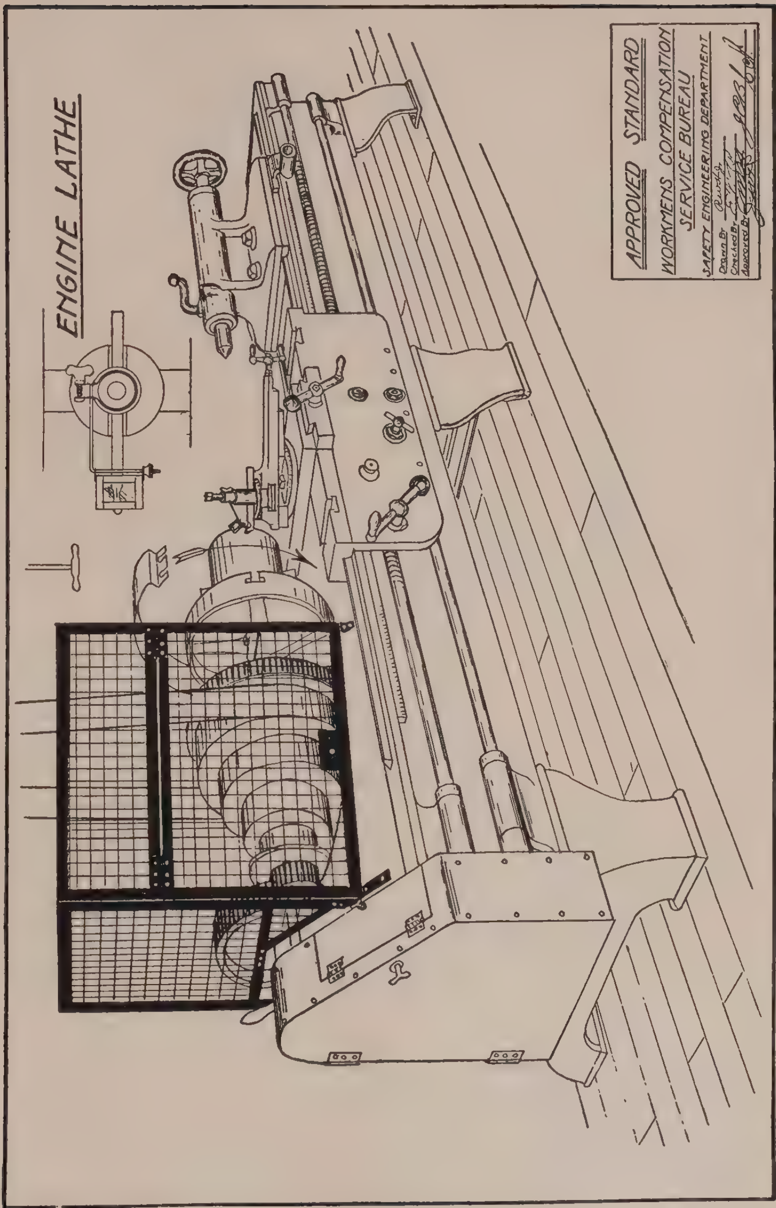
ENGINE LATHE
APPROVED STANDARD
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Fig. 9.

come in close intimacy in his work of control and operation. His fingers are in danger from the gears by which the belt or motor speed is reduced and power secured by its transformation. His clothing is liable to be caught in dogs and drivers as the work revolves and he leans over it to measure and inspect. The obvious safeguards are mesh-hoods over the headstock, which shall encompass the gears, and shields over the face-plate, along the lines shown in the illustration (Fig. 9). The turret-lathe, by eliminating the occasion for calipering the work, and by putting the permanently adjusted tool in place of one that has to be set frequently, has brought in safety with its increased production.

The emery-wheel as a grinding or sharpening machine and as a machine to produce accurate surfaces is really in two classes. It is as a grinding machine that its danger is most insistent, since the operator will be in or near the plane in which the somewhat fragile disk is revolving, and in which it will throw its pieces in case of fracture in use. It is in grinding, as sharpening, that pressure is brought against the disk in directions in which it is not most resistant. The emery wheel is also an example of machines which are dangerous to the health of the operator, by reason of the particles of the abrasive of which the wheel is made and the metallic particles ground from the work-piece. Hooding the wheel with a material strong enough to keep in the missile pieces of a broken wheel, except only at the working sector of its circumference, as shown in Fig. 10, is one way to lessen accident; and another way is to grip the wheel disk between flanges which are not parallel to each other, as respects the faces which hold the wheel, but are so shaped that the faces are farther apart at the shaft than at their outer edges. If the wheel is also convex on its faces to fit these flanges, it is obvious that segments of the wheel, in case of a break, cannot get out of the grip of the flanges, because these are nearer together at their outer edges than at the central portions. Furthermore, by connecting the hood by a pipe or duct to an exhaust-fan system, and keeping the lowered pressure in the pipe less than the resultant pressure of atmosphere and centrifugal force, the motion of particles will be from without inward and away from the respiration area of the operative.

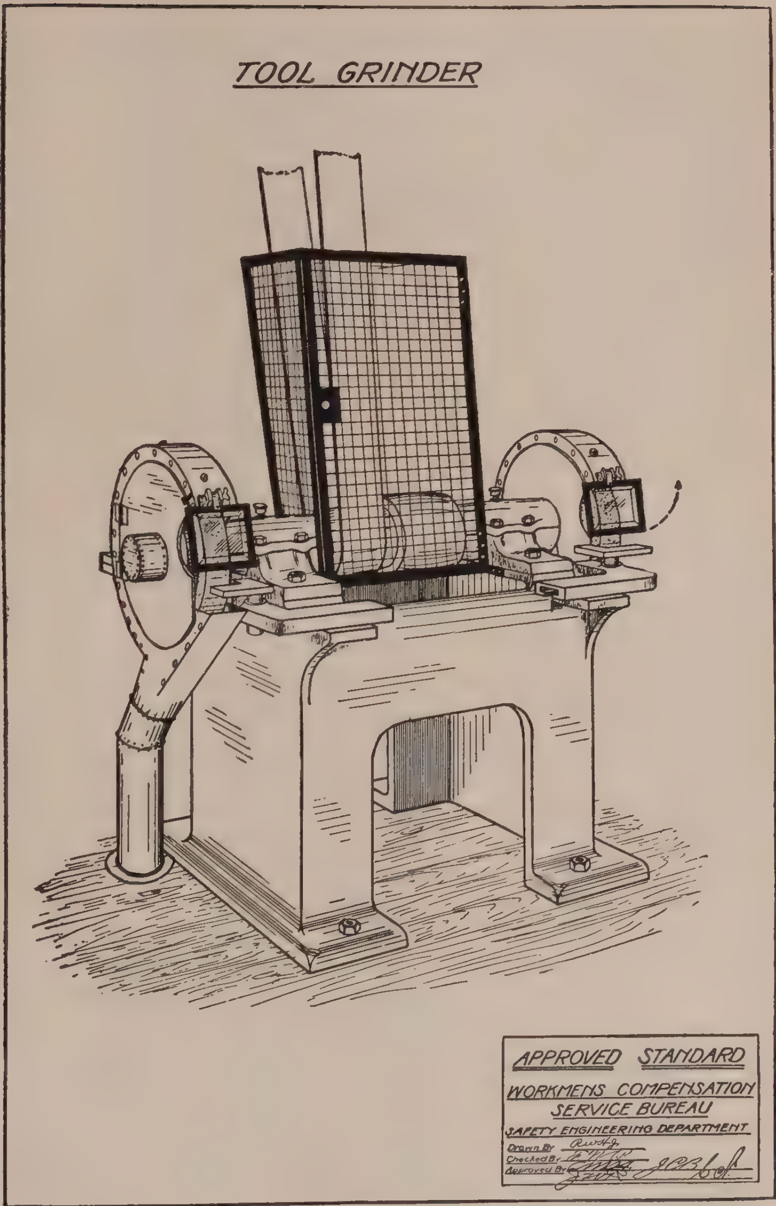
TOOL GRINDER
APPROVED STANDARD
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Fig. 10.

V. SAFEGUARDING THE FOUNDRY.

The dangers in the foundry, and the safeguards therefrom, must be only alluded to, by reason of the limits set arbitrarily to the scope of this paper and by the time appropriate to allot thereto.

The risks are from the poisonous gases on the charging floor; from the hoisting apparatus leading to the charging floor; from falls from such upper level; from the molten metal in its ladles and the latter hung by chains or upsetting from a failure of the tilting mechanisms; from the chipping and power-cleaning of the castings by emery-wheel or tumbling-barrel; from failure or derailment in the overhead trolley system, if such is used for light ladles; and from sparks and globules of hot metal reaching the eyes. An illustration of a guarded crane will be suggestive as a type of what is to be secured (Fig. 11).

VI. CONCLUSION.

In review and in conclusion, may the author call attention again to the necessarily narrow scope of the treatment possible and to the wideness of the possible area of productive activity which has received no attention whatever. The forge and the rolling mill, the steel works and the blast furnace, the saw-mill and the chemical process plant, the textile mill and the dye-house, the electric furnace and the power-transmission line and switches—each offers its own problems and all have found their satisfactory safeguards. Then there are the dangers of the quarry and the mine, of the tunnel and the subway, of the railway and the marine transportation systems, which belong to what has been called above the ''outdoor'' class, and to which no consideration has been given: and the very important subject of the safety engineering as respects fire in industrial establishments, involving both water-supply and the sprinkler engineering, and the drill of work-folk in face of danger has been passed over entirely. The author has no illusions that the treatment given has been exhaustive or satisfactory. The purpose of the paper will have been served if it shall have drawn attention once more to the character of the needs in a standard plant, and to the directions along which safety has been sought and the methods of safety designing.

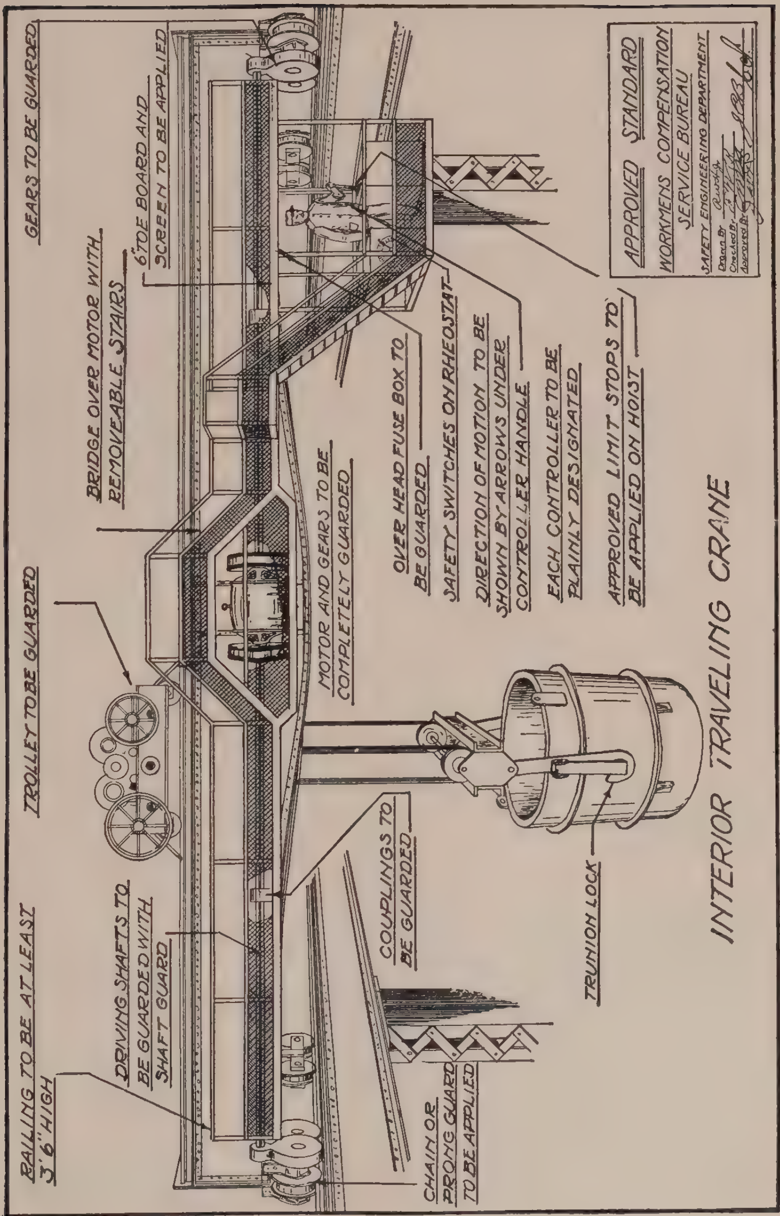
GEARS TO BE GUARDED
6" TOE BOARD AND SCREEN TO BE APPLIED
BRIDGE OVER MOTOR WITH REMOVEABLE STAIRS
TROLLEY TO BE GUARDED
RAILING TO BE AT LEAST 3'6" HIGH
DRIVING SHAFTS TO BE GUARDED WITH SHAFT GUARD
CHAIN OR PRONG GUARD TO BE APPLIED
COUPLINGS TO BE GUARDED
MOTOR AND GEARS TO BE COMPLETELY GUARDED
OVER HEAD FUSE BOX TO BE GUARDED
SAFETY SWITCHES ON RHEOSTAT
DIRECTION OF MOTION TO BE SHOWN BY ARROWS UNDER CONTROLLER HANDLE
EACH CONTROLLER TO BE PLAINLY DESIGNATED
APPROVED LIMIT STOPS TO BE APPLIED ON HOIST
TRUNION LOCK
INTERIOR TRAVELING CRANE
APPROVED STANDARD
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Fig. 11.

The author would speak most appreciatively of the help and cooperation of the American Museum of Safety of the State of New York, and, in the matter of the illustrations used, of the courtesy of Mr. Carl M. Hansen, Member of the American Society of Mechanical Engineers and of his consent to reproduce copyright drawings of the Workmen's Compensation Service Bureau for the purposes of the Engineering Congress. These have been created by him and his colleague engineers and hearty and sincere thanks are hereby extended.

And, after all, when the designer and creative engineer have done their utmost, there will remain the function of the administrator to create an atmosphere in the plant and among the work-folk which shall make safety in operation an ideal of each individual. This object has been sought by many means, but probably the most effective is the organization of Safety Committees of the workmen, particularly, when the latter speak many vernacular languages. It is the duty of such committees to see to it that safety appliances are used when provided, and that the man is fully advised in his own speech as to safety to himself and his companions. The reckless and indifferent, by a pressure from his own associates, must not be allowed to take chances, when a mischance would cost the life or earning power of the careful and the innocent who would be involved in the disaster. In a word, the process is one of Education, and then **more** Education. If this paper shall be usable for the end which it seeks, its preparation will have been justified.

DISCUSSION

Mr. Dickie. **The Chairman, Mr. Geo. W. Dickie,*** Mem. Am. Soc. M. E., opened the discussion by remarking that it is almost inconceivable the risks men will sometimes take. He recalled the case of a carpenter who seated himself on the overhanging end of a plank, which he intended to cut off, making the saw cut between himself and the support, thus "cutting himself off". Remarkable to state, a court held the employer liable for $5000 damages. Protection is now so complete that a man has to go out of the ordinary execution of his work to get hurt.

The matter of insurance has been better handled in Europe than in the United States. In Sweden, for instance, the industries are arranged in groups, and each group has to pay its pro rata of the cost of accidents.

* Consult. Engr., San Francisco, Calif.

By this method the cost of insurance has been reduced to one tenth of one percent of the pay roll. In this country it is difficult to get the same insurance below 6%. Mr. Dickie.

Mr. Luther D. Burlingame,† Mem. Am. Soc. M. E., recalled an accident case in which he was called as an expert. A girl in a screw factory had dropped something under her machine and in attempting to pick it up, her hair was caught in a revolving shaft and torn from her head. Also, in another case, a man who heard some unusual noise above his machine and thinking it was a loose collar rattling, attempted to adjust it, and in doing so, put his fingers among a train of gears. In both of these instances the operators did unusual things and exposed themselves in ways that would not ordinarily have been called for. Education is required to teach avoidance of such unusual accidents and two ways of doing this are open. First, teach the workman to believe that, if he takes no risks, he is a better workman; second, teach safety in the technical schools. The schools and colleges have been followers and not leaders in this respect. Appliances and physical guards have little to do with safety after all, and education is the chief thing. The great majority of accidents are now mechanical, a man may slip and fall or splinters may fly and strike the eye, which no guards will prevent. Mr. Burlingame.

Mr. R. Seshasayee,‡ Assoc. A. I. E. E., said that the Indian Government had organized a department for the inspection of factories to meet the great need of accident protection. Inspection is made periodically as to the proper protection of the machine and the competence of the workmen to look out for themselves. Exporters of machinery to India should place all safety appliances required by law upon their products. Lathes lately imported from Italy have been rejected because they were not sufficiently safeguarded. Mr. Seshasayee.

Mr. R. L. Rowley,§ Junior Am. Soc. M. E., called attention to the bad practice of housing in a large area which it was desired to protect, by the use of lumber and wooden boxing. This is resinous and highly inflammable and adds to the fire risk. It is a much better and safer plan to use metallic guards and rail. Mr. Rowley.

Mr. W. C. Lindemann,* Assoc. Mem. Am. Soc. M. E., said that it is a difficult matter to safeguard at points where machines are congested, i. e., where machines are crowded with material to be worked. Points of congestion are dangerous even to visitors going through the plant. It is also difficult, at first, to devise safeguards for machines with which the users are unacquainted. In this connection he desired to call attention to the value of safety museums for showing how. European cities have such museums and all large cities in this country should likewise have them. It is hard to carry on safety work with unreliable help. In this Mr. Lindemann.

† Industrial Supt., Brown & Sharpe Mfg. Co., Providence, R. I.

‡ Trichinopoly, South India.

§ San Francisco, Calif.

* Milwaukee, Wisconsin.

Mr. Lindemann. respect labor falls into two classes—desirable and undesirable. A workman may come to his work unfit for it, on account of drink. The sooner employers get rid of these, the sooner will accidents cease.

Mr. Rosenthal. **Mr. J. J. Rosenthal,**† Assoc. M. Am. Soc. C. E., said that he had not noticed that safeguarding on construction work had been touched upon in this paper. He had met superintendents and engineers who had said that it was impossible to safeguard construction work. It is possible to safeguard machinery on construction work and to inculcate the slogan "safety first", just as in a factory. Teach workmen to employ scaffolding, false work, etc., of suitable strength.

Prof. Hutton. **Prof. F. R. Hutton,** in closing, expressed gratification over the interested comment in the foregoing discussion, and desired to express his appreciation therefor.

Construction work, referred to by Mr. J. J. Rosenthal, is usually in the "outdoor" class, and was for that reason expressly excluded from treatment. But the speaker is right in the general comment that this class of safeguarding has not received the attention which it deserves. There may be two reasons for this. One is that such work, in the general case, is by nature temporary as compared with the factory condition; and as respects any one individual employee, it is of short duration. The other is that in the majority of cases the worker is injured either by his own fall, or by the fall on him of some object from above; that is, the worker is to be shielded from the action of gravity as a force, and this is one of the most troublesome forces to guard against. It is the man who is the possible victim who must carry the safety device with him as he moves about, while in the factory class he is to be shielded as he stands still. Difficulties from congestion and crowded spaces, spoken of by Mr. W. C. Lindemann, are not usually present under these conditions, nor those from fire, referred to by Mr. R. L. Rowley. The reference by Mr. R. Seshasayee to the advanced state of the art of safeguarding in India is particularly interesting.

† San Francisco, Calif.

Paper No. 130

MOTOR VEHICLES; PASSENGER TYPE.

By

ETHELBERT FAVARY, Mem. Soc. Auto. Engrs., Mem. Aero. Soc.
New York, N. Y., U. S. A.

It is the object of the author to give within the space allotted by the Engineering Congress as comprehensive a view as possible of present construction of the different parts forming the motor car of today, yet the whole treatment is necessarily limited owing to the brevity of this paper.

ENGINES.

Within the last few years the short-stroke high-speed engine has been superseded by the long-stroke engine. The average stroke-bore ratio of the present American practice is about 1 1/3 to 1. While the average theoretical power of engines has been decreased somewhat in the 1915 models, the engines, nevertheless, give a higher power, due, no doubt, to the better balance and lighter reciprocating parts, and other improvements to be mentioned later. With these improvements and refinements, the engine speed could be appreciably increased; however, to obtain the best efficiency in the long run, with the most comfort and the least vibration, the engine should be run at not too high a speed under ordinary conditions.

One of the recent tendencies in engine design is to cast the cylinders en bloc, and to have separate heads attached thereto. With the separate cylinder heads, the user finds it more efficient and convenient to take off the head, scrape the carbon from the cylinders, grind the valves; also he finds the removal of pistons and connecting rods facilitated.

The separate head offers important manufacturing advantages by enabling the upper half of the crank case, or the crank

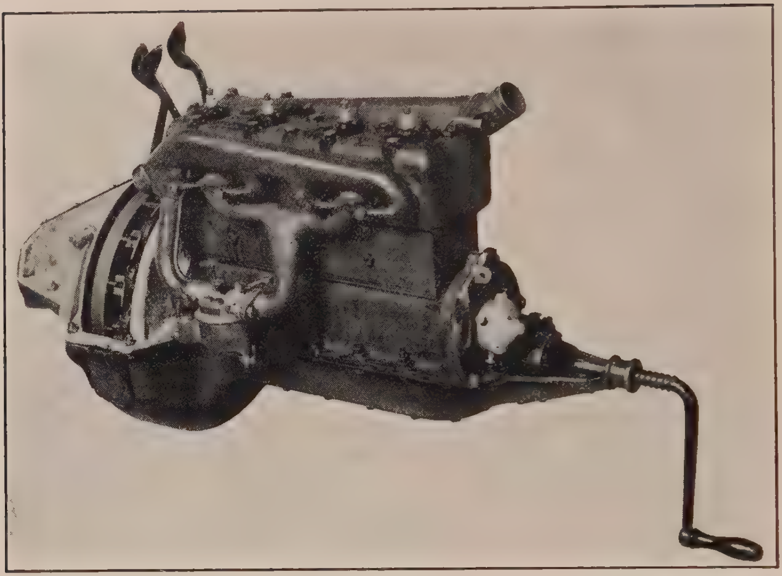

Fig. 1. Ford Engine. Cylinders cast en bloc with upper half of crank case. Detachable cylinder head.

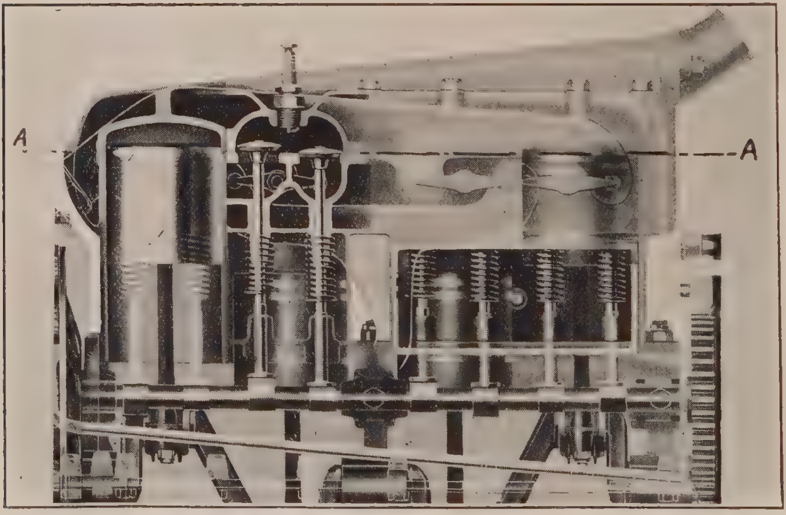

Fig. 2. Sectional view of Fig. 1.

case entire, to be cast with the cylinders en bloc. This saves several machining operations, and by making it possible to properly support the core, it insures a uniform thickness in the cylinder wall, thus permitting such wall to be cast much thinner without danger of defects. It is also a more economical construction, as the crank case is made of cast iron instead of aluminum, which is more expensive; by casting the crank case en bloc with the cylinder, the heavy flanges or joints between cylinder and crank case are obviated, thus saving about the same weight as is due to the use of cast iron instead of aluminum. With the detachable head, the entire combustion chamber can be machined, thus insuring absolute uniformity in the volume of all the cylinders. Over 30% of the present American models employ the separate cylinder head, and manufacturers continue its adoption for both the four- and six-cylinder engines. Fig. 1 (Ford) shows a side view of the engine of the most successful small car in this country. The cylinders are cast en bloc with one half of the crank case. Fig. 2 gives a sectional view of the same engine; the ''separate cylinder head'' being removably attached at line A—A. Note the compactness and simplicity of the entire construction.

Mono-bloc castings are employed today for even the largest motors, but especially for the four-cylinder engines. A large number of the sixes are cast in two sets of three; this relates especially to the greater horsepower six-cylinder engine, which, on account of the size, is more difficult to cast in a unit with the crank case. Fig. 3 (Hudson) shows a six-cylinder engine with the cylinder cast in two sets of three, bolted to the aluminum crank case. Fig. 4 (Marmon) shows the crank case used in connection with bolted-on cylinders. In this instance, the entire crank case, with the exception of the oil reservoir forming the bottom plate, is in one piece. By casting the motors en bloc, the engine length can be reduced, which, in turn, permits a reduction in the length of the wheelbase, or an increase in the body length without increasing the wheelbase. Block casting facilitates the enclosure of every moving part, thus tending toward silent running and rendering the exterior of the engine simpler and neater. Until recently, it was feared that difficulties might be encountered in the foundry in casting these cylinders en bloc; improve-

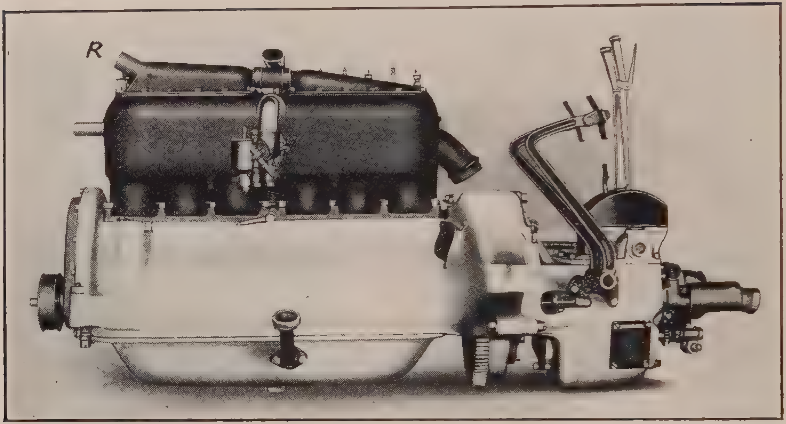

Fig. 3. Hudson Engine. Cylinders cast in two sets of three; bolted to crank case.

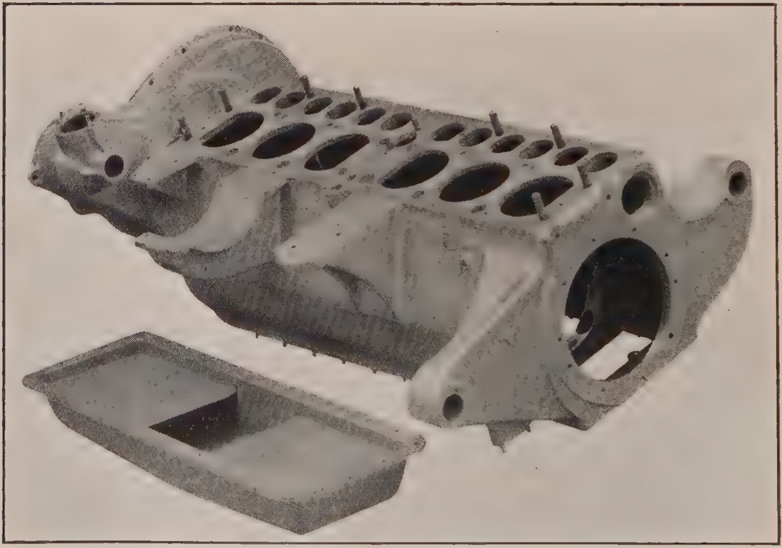

Fig. 4. Marmon. Crank-case casting.

ments made in foundry work have shown this fear to be groundless, as the results speak for themselves. Over 70% of the four-cylinder engines are cast en bloc, and about 40% of the sixes. An engine cast en bloc with separate heads is also more accessible than if cylinders are cast separately and removably attached to the crank case.

American practice favors the "L"-head cylinder. (See Fig. 2.) One reason for its rapid adoption may be traced to the block casting, which is more suitable for this type. About 70%* of the engines of the 1915 models have "L"-head cylinders, and it is fair to predict that "L"-head and mono-block cylinders will soon be the outstanding feature of American standard practice.

The four-cylinder engine is still used in the majority of present models, but the six cylinder has been gaining ground rapidly, and is employed in about 47% of the models. One prominent maker placed an eight-cylinder engine on the market several months ago; since then five or six other eight-cylinder designs have made their appearance, or have been announced to come out during 1915.

The advantages of the six-cylinder over the four-cylinder engine are, primarily, the torque and the more perfect running balance, hence allowing driving at low speeds without the jerking so noticeable in the four-cylinder engine. Practice, however, has demonstrated that the efficiency of the four-cylinder is higher than the six. The chief losses in the six are, no doubt, due to the larger jacket area, the greater loss due to friction and, probably, some loss due to exhaust back-pressure when employing one exhaust pipe, which is the usual practice. Roughly speaking, in the six-cylinder engine about 20% more area is exposed to the cooling water than in the four-cylinder engine, and as about one half the heat units of the fuel is lost through the jacket, the great amount of the loss due to this increased area can be fully appreciated. In order to overcome the increased losses in heat units and in friction in a six-cylinder motor requires, in practice, between 10% and 15% more fuel than in a four-cylinder engine of the same horsepower, design and given load. The jacket losses are proportionately greater

* The Automobile, December 31, 1914. (A number of the percentages have been taken from this issue of The Automobile.)

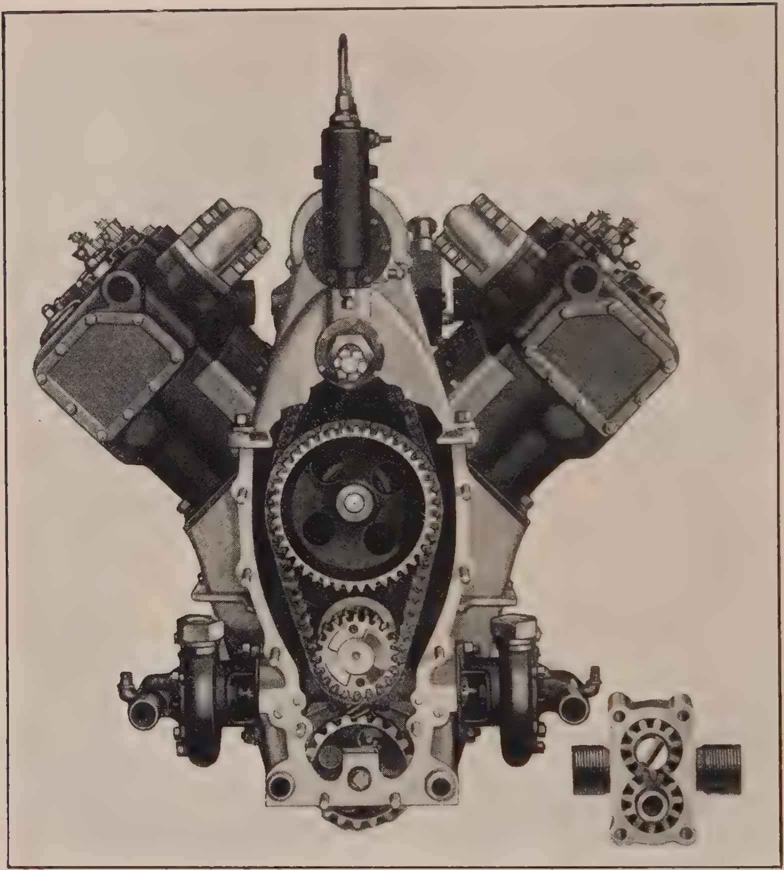

Fig. 5. Cadillac eight-cylinder V-type engine. (Front view)

at light loads, consequently, unless the sixes are used at full loads, these losses will be even greater; since six-cylinder engines are, as a rule, higher powered than fours, the losses, in practice, are larger than given above. Nevertheless, the advantages of the six, from the user's standpoint, namely, the increased and uniform torque, outweigh the economic fuel advantage, as is proven in practice by the increasing demand for sixes, year by year.

The advantages of the eight-cylinder engine are more engine power with a given engine length—since the eight-cylinder

is usually built "V" shape, i.e., the cylinders are arranged in two sets of four, at an angle of 90°. (See Fig. 5, Cadillac.) In reducing the length of the engine, weight is saved in the crank case casting, crank shaft, etc., besides the weight saved in the chassis, which makes possible the shortening of the wheelbase. Theoretically, the eight-cylinder engine has a better and more uniform torque and the reciprocating parts are in absolute balance, thus avoiding the chief cause of vibration in the four-cylinder type. There being four explosions in each revolution of the crankshaft, such an engine should be more flexible.* The disadvantage of the eight-cylinder engine is the increased fuel losses due to the greater area exposed to the heat. For a given

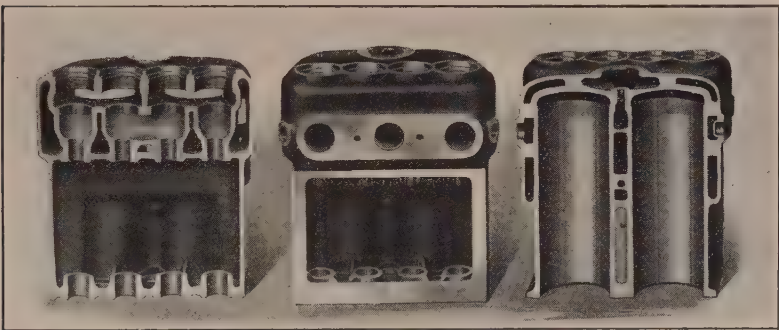

Fig. 6. Mitchell. L-head cylinder casting showing spacing of valves and water jacket.

power the cylinders would be considerably decreased, and by decreasing the bore the valve area is reduced, which offers higher frictional resistance to the inflowing gas. Another disadvantage is the multiplicity of parts; and it is, at this time, simply a conjecture whether the manufacturers of eight-cylinder engines will be able to bear out their claims.

VALVES.

With separate cylinder heads, it is possible to increase the diameter of the valves somewhat, as it is feasible to place the valves closer together. (With integral heads allowance must be made for the width of the bridge between adjacent valve blocks.)

* See Horseless Age, Sept. 16, 1914, P. M. Heldt, for torque, etc., of eight-cylinder engine.

With the practice prevalent today in the "L"-head engine, both valves are of the same size, and as they are both fitted into one port or cylinder neck, the valve diameter is necessarily limited. (See Fig. 6, Mitchell.)

With the "T"-head cylinder, it is possible to increase the valve dimensions, but thereby the heat losses are increased because of the larger area exposed to the heat. Valve dimensions are a very important factor in obtaining high efficiency at high speed. In finding the correct area for valves, the cylinder stroke as well as the bore should be considered, and not, as is frequently done, consider the bore only. Heretofore, with the short-stroke engines, where bore and stroke were alike, it has been considered good practice to make the diameter of the valves 40% to 45% of the bore; now that the stroke is longer—and high speed with high efficiency is sought—manufacturers find it necessary to increase the valve diameter.

Outside of block castings, no doubt one large factor for the increased use of the "L"-head cylinders is economy in production, as with this type the valves are all on one side, requiring one cam-shaft only. The "I"-head cylinder having the overhead valve (which is used by a few manufacturers) permits the employment of larger valves and allows the valves to open directly into the cylinder. With the "I"-head, a more efficient fuel economy is possible by eliminating the area of the valve ports, and thus reducing the heat losses; however, it is more expensive to manufacture and the valves are not so accessible. (See Figs. 7 and 8, Buick.) In making the "I"-head motor with a detachable head, this difficulty has been overcome in one of the 1915 models, where the entire mechanism, including the cam-shaft, is placed overhead. (Chalmers.)

The original drive for the cam-shaft was by means of ordinary spur gears from the crank shaft to the cam-shaft. To overcome the defect of noise in this type, helical gears were developed, where the teeth, instead of running parallel with the axis of the gear, form a helix, making an angle of 30° with the axis. The helical gear transmits the power more uniformly as the entire tooth does not come into, nor out of, engagement at the same time. The helical gears, however, produce an end thrust, which must be provided for. (See Fig. 9, Pierce-Arrow.) A

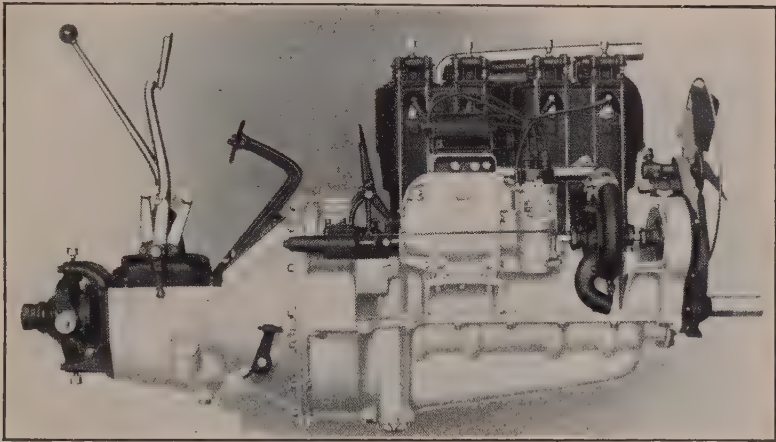

Fig. 7. Buick. I-head cylinder with overhead valves, showing valve lifting rods on outside.

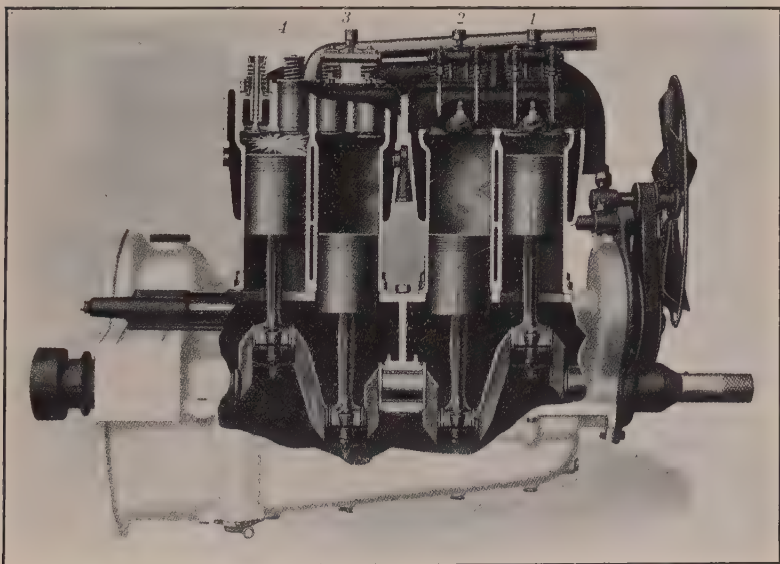

Fig. 8. Section through Fig. 7.

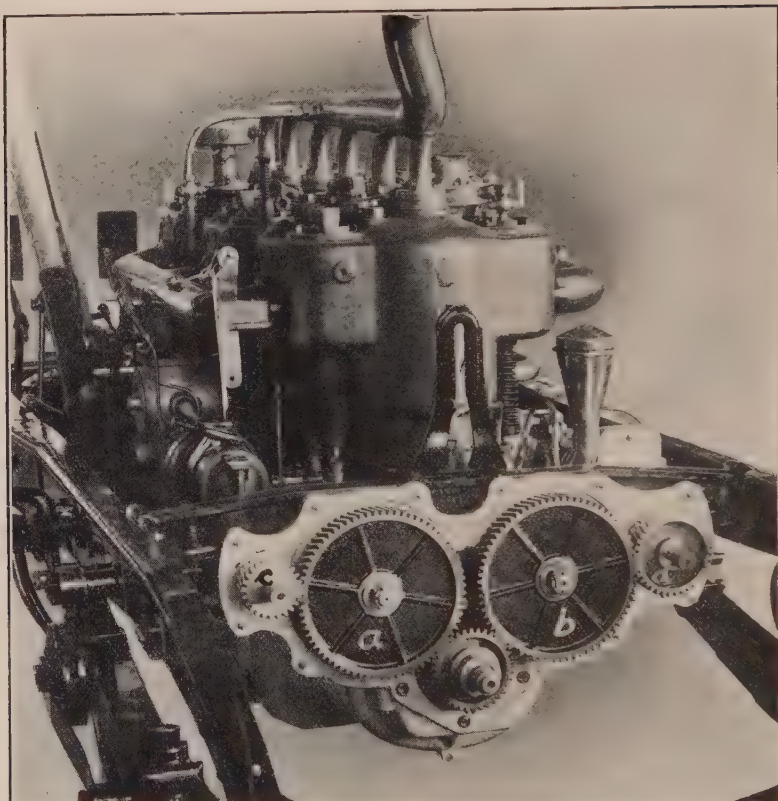

Fig. 9. Pierce-Arrow. T-head engine. Helical spur gears for cam-shafts.

number of makers have adopted the silent chain drive for the cam-shaft. (See Fig. 5.) These chains, when they wear and have increased their pitch, do not affect the fit of the chain teeth on the wheel-teeth. However, almost three fourths of the models employ the helical spur gears, which must thus be considered the standard practice.

From statistics* compiled for this year's practice, the average timing of the inlet valve on the latest models shows that it opens at about 11.50 past upper dead-center, and closes at 37.30 past the lower center. The exhaust valve opens at about 46.90 before lower center, and closes at 6.50 past upper center.

* The Automobile, Dec. 31, 1914.

The average inlet-valve closure is somewhat later than in former models, the intention, no doubt, being to make use of the inertia of the incoming gas to bring a larger volume of fresh mixture into the cylinder.

The average opening of the exhaust valve is about 3° later in the 1915 models than in last year's, and, no doubt, the long-stroke engine is responsible. With an increased engine speed, the opposite would have been expected; for with a higher piston speed, it would be deemed advisable for the exhaust valve to open earlier in order to reduce the pressure in the cylinders to atmospheric pressure by the time the piston reaches the end of the stroke.

The closure of the exhaust valve in the latest models is about 3° earlier. This indicates a tendency toward the increase of the negative valve-lap, it having increased from minus 1.9° in last year's models, to minus 5° in the present models. The positive lap—i.e., where the intake and exhaust remain open at the same time—has decreased, at the present day being used in only about 10% of the models, whereas 70% use the negative lap and about 20% the zero lap—viz., where the inlet valve opens simultaneously with the closing of the exhaust valve. With the negative lap—where the inlet valve opens after the piston descends for some distance on the suction stroke—the fresh charge will flow into the cylinder at a higher speed on account of the partial vacuum in the cylinder at that instant. Heretofore, it has been held that the positive lap could be used for this purpose, as the inertia of the exhaust gases through the exhaust port would create a certain vacuum in the cylinder, and thus have the same effect. The change in the tendency toward the use of the negative lap may be accounted for by the increase of the "L" head, where both valves are side by side.

In the "T" head—where the ports are on opposite sides of the cylinder—the inertia of the exhaust can be used to advantage, since after the inlet valve opens, it would take some time before the fresh gas is carried across the cylinder to the exhaust port. In the "L" head, where the valves are close together, the positive lap would cause the fresh charge to flow right out through the exhaust valve.

The valve in most general use today is the poppet valve.

The advantage of this valve is that it does not require lubrication, and when leaks develop, can easily be ground into its seat. Recently, great improvement has been made in the valve itself, by using tungsten or high-speed tool steel in its construction; this steel withstands the abrasive action of the hot gases much better than ordinary steel, thus increasing the life of the valve as well as eliminating the necessity of frequent attention.

The disadvantage of this type is the inertia of the valve and the parts which move it, hence it cannot be moved to a high velocity quickly, nor can it immediately be brought to rest, without undue strain and noise. The advantages of the non-poppet valve types, as, for instance, the sleeve valve in the

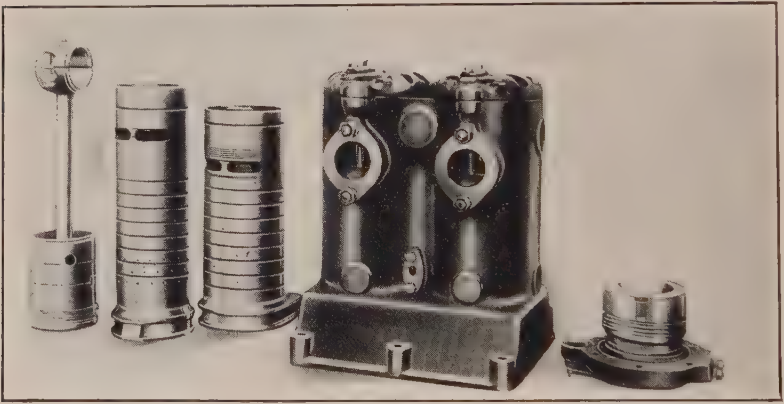

Fig. 10. Willys-Knight engine showing valve sleeves and cylinder head.

Knight engine (see Fig. 10, Willys Knight), are that the valves may be opened and closed more quickly, and run more quietly. With this type, the valve is in motion when it begins to uncover or to close the port. However, of late years, the poppet valve has been made more silent in operation by improvement in the shape of the cams, stiffening the cam-shafts, and enclosing valve springs and tappets. With sleeve-valve engines, there is an increased power for a given piston displacement, due primarily to the larger valve area, the increased speed in opening and closing the valves, and to the feasibility of making the combustion chamber spherical, thus having the smallest area exposed to the gas for a given cylinder volume, hence, reducing

the heat units lost to the wall. In the sleeve-valve engine, the pressure of the expanding gases against the valve sleeve is self-contained, whereas with the poppet type, the exhaust valve is opened with a comparatively high pressure on its head. Fig. 10 shows the two sleeves exposed.

PISTONS.

Pistons have been increased in length and, at the same time, lightened in weight. This was made possible by a more perfect core work, making the wall and the webs thinner. A big reduction in weight has also been made in the piston rings, the present tendency being to have a smaller number of rings at the top of the piston, the rings having been rendered more efficient by the employment of composite rings, i. e., laminated, or made up of several layers. (Present practice favors the purchase of certain special features from specialists, piston rings being one instance.) This improved piston ring prevents leakage to a much greater degree, and thus a smaller number need be employed. While in the single rings lap joints are used, in the laminated rings the laps are staggered, and hence overcome leaks, at the same time increasing the life of the ring.

CONNECTING RODS.

For connecting rods, the use of alloy steel is very common, especially chrome-vanadium and chrome-nickel steel. However, many of the low-priced cars use the open-hearth carbon-steel. By employing alloy steel, the connecting rod can be made light, yet strong, thus reducing the reciprocating weight, and thereby minimizing the vibration; the "I"-beam-section connecting rod being most commonly used.

CRANK-SHAFT AND BEARINGS.

The tendency today is to use the smallest number of crank-shaft bearings possible—two bearings for four-cylinder and three bearings for six-cylinder engines. The block cast cylinders and the decrease in cylinder bore would further indicate the trend in this direction.

In order to eliminate torsional vibrations, it has been found

necessary to make the crank-shaft stiffer, and by so doing, the number of bearings could be reduced. This permits the shortening of the shaft, which, with the block-cast cylinder, is an advantage; no doubt the reduced cost also has a bearing on this tendency, and it is fair to predict that American standard practice will have two bearings for the four- and three for the six-cylinder engines. The trend in that direction during the last twelve months has been especially noticeable in the six-cylinder engines, as even last year the four-bearing type was still in preponderance. Fig. 11 (Chandler) shows the crank-shaft and pistons of a six-cylinder engine, with three bearings.

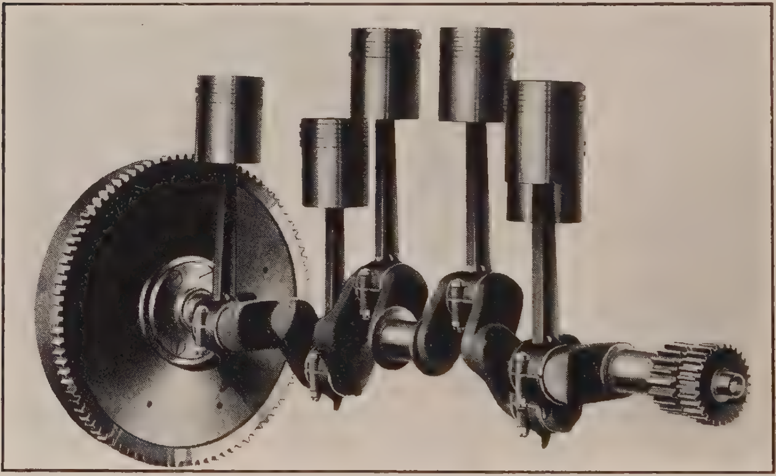

Fig. 11. Chandler crank-shaft and pistons.

The seven-bearing type which was formerly used in the sixes is losing ground very rapidly. With the requirement for a stiffer crank-shaft, the diameter of the crank-shaft has been increased; this, however, means a higher peripheral speed of the bearings. In order to reduce the diameter and the weight, and still have sufficient stiffness in the crank-shaft, chrome-nickel steel or vanadium steel are coming into use more and more. By giving these special steels careful heat treatment, the tensile strength in a comparatively small shaft is remarkable; at the same time it has sufficient stiffness to overcome

torsional vibrations at high speed. However, due to the very important matter of price, no doubt, the largest number of models still employ the 0.40 carbon open-hearth steel for crank shafts.

With the higher speed and the smaller number of bearings, it has been found necessary to increase the bearing length; this is especially important in the rear bearing near the fly wheel; the more so, as most engines are now being equipped with self-starters, and it is important to increase the length of this bearing to take the side thrust.

COOLING AND FUEL ECONOMY.

While the pump circulation is used in about 72% of the models on the market, the recent tendency is to adopt the thermo-syphon, which is made use of in 27% of the 1915 models. In some of the new designs, a larger water jacket, and thus a greater volume of water around the cylinders, is provided. Whether practice will continue in this direction is questionable, since too much cooling reduces the efficiency—except in mountainous countries, where it is advantageous to have sufficient cooling to prevent overheating.

Fig. 6 shows how the water jacket is usually arranged around the valves and the combustion chamber. The low fuel economy in motors is very frequently due to excessive cooling, i. e., to the low temperature of the engine. The ideal motor should have the cooling so controlled as to bring the water very quickly to a temperature near the boiling point, and then remain there. When the water boils, rapid evaporation takes place, with the concomitant overheating. Experience has shown that on long trips, when the engine has become thoroughly warm, a higher fuel efficiency is obtained than when making short trips with frequent stoppages of the engine. In the thermo-syphon system, the water in the water-jackets of the engine sooner reaches a high temperature, but it also boils away more quickly in mountainous countries and in traffic. However, when stopping the motor it cools rapidly, as the circulation of water between radiator and jacket continues.

With the pump circulation, the flow of water is practically checked when the motor—and thus the pump—ceases to rotate,

thereby retaining the heat near the motor, even though the radiator cools rapidly. When re-starting the engine, the temperature is higher to begin with, besides making starting easier. Air-cooled motors have shown an exceptionally good fuel economy, due principally to the high temperature of the engines, or the absence of severe cooling means. Probably due to the increase in manufacture of the small low-priced cars, the thermo-syphon system is being used more extensively, but the pump system is still employed in about 75% of all the models. Fig. 3 shows a neat arrangement of the water pipe leading from the cylinders to the radiator at R, while a more common construction can be seen on Fig. 9.

FUEL FEED.

One of the most radical changes seen in the 1915 models has been in the fuel feed. Hitherto, either the pressure feed—i. e., pressure in the gasolene tank—or gravity feed has been used for supplying the fuel from the gasolene tank to the carburetors. Most of the systems using the gravity feed have tanks in the cowl. The disadvantage of the gravity feed is that the carburetor has to be placed very low, thus increasing the length of the intake manifold. The cowl tank is also disadvantageous on account of the restricted space for its disposition and limiting the space for the occupants; besides, on account of the odor of gasolene which may run over or spill when filling the tank. By taking the tank away from beneath the seat, it enables the latter to be made considerably lower, with deeper cushions, thus following the tendency of giving the occupants increased comfort. During the past year, the vacuum fuel-feed has come into vogue, and appears on more than one quarter of all the 1915 models. A further tendency is to remove the gasolene tank from under the seat.

One distinct advantage offered by the vacuum-feed system is that all cars may have the tank in the rear; the results so far achieved with this system have been most satisfactory, and it is fair to predict that it will soon be the standard adopted by manufacturers. With this system, the carburetor can be placed in the most accessible position, while the tank, being in the rear, does not interfere with the occupants of the car. In the

vacuum-feed system, a pipe runs from the inlet or intake manifold to the upper chamber of a small auxiliary tank (Fig. 12, Stewart) under the engine bonnet. The lower chamber is con-

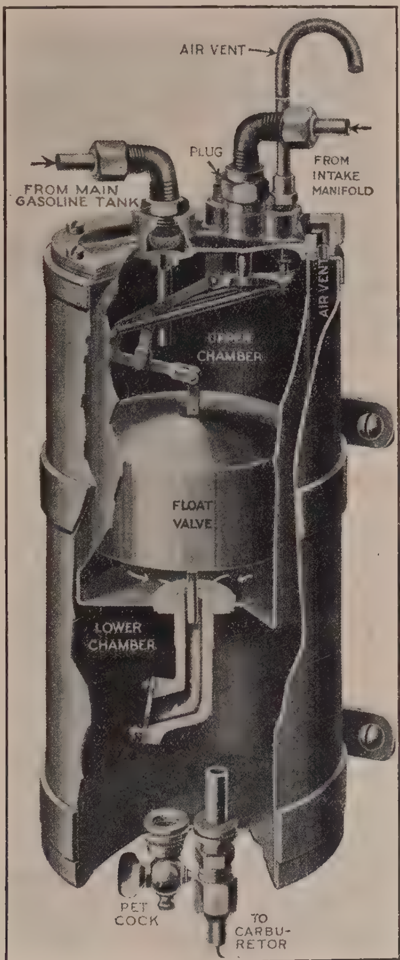

Fig. 12. **Stewart vacuum-feed system.**

nected with the carburetor. The vacuum created by the intake stroke of the engine draws the gasolene from the gasolene tank into the upper chamber. The float determines the height of the

gasolene therein by shutting the vacuum valve, and opening an air valve at the same time, whereupon the gasolene flows into the lower chamber. When the float descends below a certain point the vacuum valve is opened again, and the process of refilling the upper chamber begins anew. The lower chamber being open to the atmosphere, the gasolene flows to the carburetor by gravity in the usual way.

It is fair to state, however, that the gravity feed is at present still used more than any other system.

LUBRICATION.

Splash lubrication—i. e., lubrication where every bearing surface of the motor, including cylinders, pistons, crank-shaft bearings, cam-shaft, wrist pins, and timing gears, are lubricated from the splash—is made use of in about 50% of the 1915 models. In the splash system, it is customary to feed the oil by a pump through a trough at the bottom of the crank case.

The pressure-feed system, where the oil is taken from a reservoir by pump and is forced under pressure to all the bearings—i. e., entering the hollow crank-shaft, it flows to the lower connecting-rod bearings, from there through hollow leads to the wrist pin and thence to the cylinder walls, is used by a number of manufacturers. In this system, the cam-shaft and timing gears are also fed by pressure through independent leads.

In a large number of models the splash-pressure system is employed, in which, as a rule, the oil is carried under pressure to the main crank-shaft bearings, the overflow being utilized to fill the trough for the splash, which lubricates all other surfaces or bearings. There are variations, however, in this system; in some cases the cam-shaft bearings are lubricated direct, and in others the cylinder wall is provided with oil under pressure.

CLUTCHES.

A recent tendency is toward the employment of the dry disc clutch, where a number of plates or discs are faced with asbestos fabric. This type of clutch (first developed as the

single plate, which is still used by a number of manufacturers) is applied to about one third of all the models, either with a single disc or a number of discs. The cone clutch, however, is still used very largely, in fact, on almost one half of all the models on the market—no doubt on account of its simplicity. While in former years this clutch was always covered with leather facing, recently the tendency has been to adopt asbestos facing. In the cone clutch great improvements have been made in lightening the cone by the employment of aluminum or pressed steel. The disadvantage of this clutch is its small frictional surface, thus necessitating a large diameter of the cone, which means a large amount of inertia, and hence, interference with the meshing of the gears. However, with the improvements just mentioned, these objections have been overcome to a large extent. Fig. 13 (Maxwell) clearly shows the simplicity of this type. In some designs a number of small auxiliary springs are placed under the leather facing to obviate a too sudden grip.

The multiple-disc clutch (Fig. 14), which was in great vogue, has been abandoned to a large extent, owing to the difficulties of lubrication, etc. This clutch, on account of its small diameter made possible by the employment of the number of plates, had a very low inertia, but the difficulties have been chiefly due to the lubricant, on account of the viscosity changes with varying temperatures. When the oil is not sufficiently fluid, the clutch drags, because of the small release motion between the discs making the meshing of the gears more difficult. With oil too thin, the action of the clutch will be too sudden or too fierce, thus starting the car with a jerk.

To avoid these troubles, the dry type of disc clutch has been developed, and is giving very good satisfaction on account of its smooth action and low inertia; since asbestos is not affected by heat or high temperatures, it is not damaged by the slipping of the clutch. Practice has demonstrated that this clutch does not drag, and as the asbestos facing is yielding, jerking is overcome, although higher pressure between the plates is employed. Fig. 15 (Packard) shows assembly and section of a dry plate clutch employed by a well known make of car. As seen, there are two series of plates which are alter-

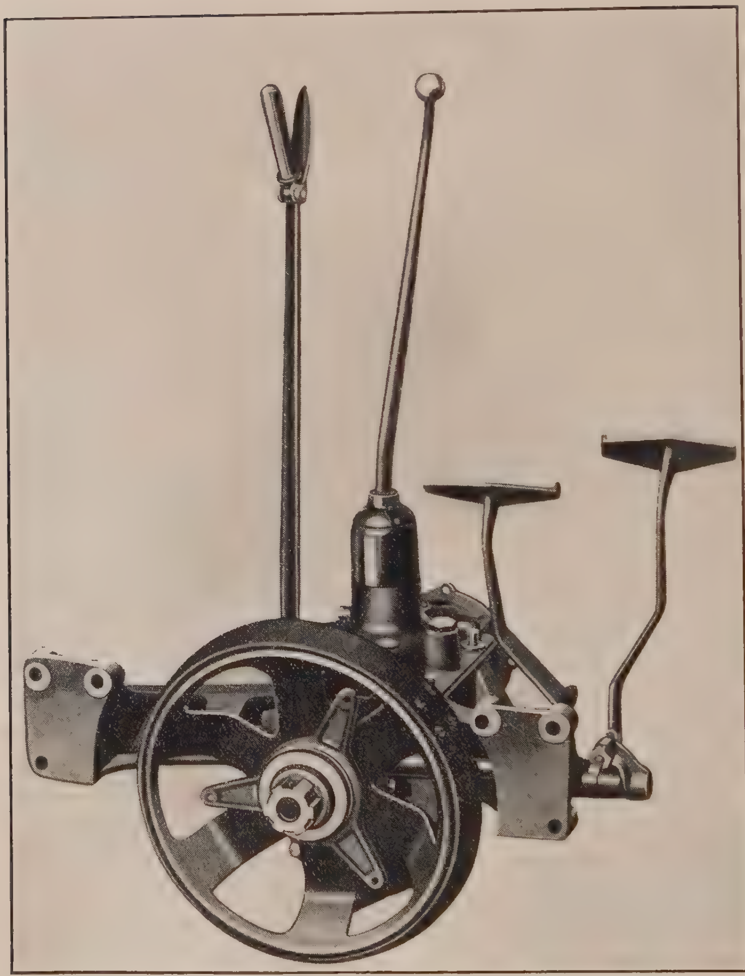

Fig. 13. Maxwell cone clutch, asbestos faced.

nately connected with a casing "C" attached to the fly wheel—and the spider "S" attached to the clutch shaft. The casing plates are faced with friction material which contacts the steel plates attached to the spider.

In a number of the 1915 models, the clutch brake is used to enable a smoother meshing of the gears. This clutch brake

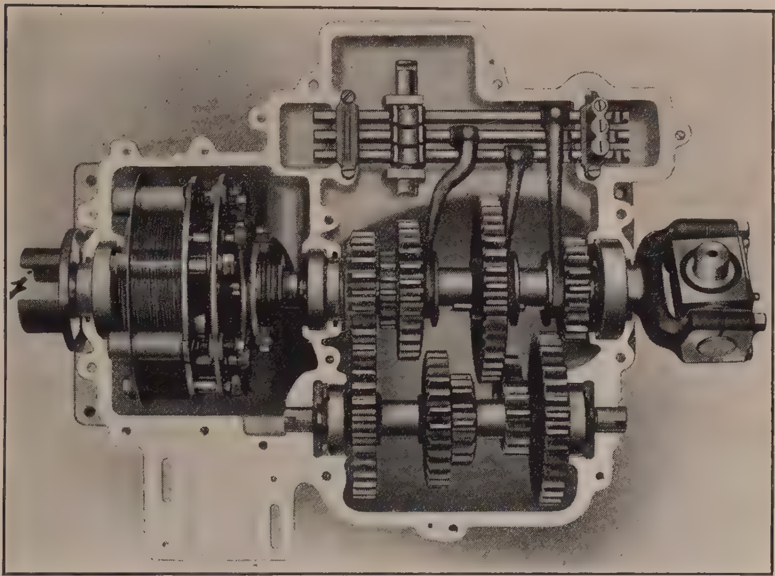

Fig. 14. Winton. Multiple-disc clutch with transmission in one housing.

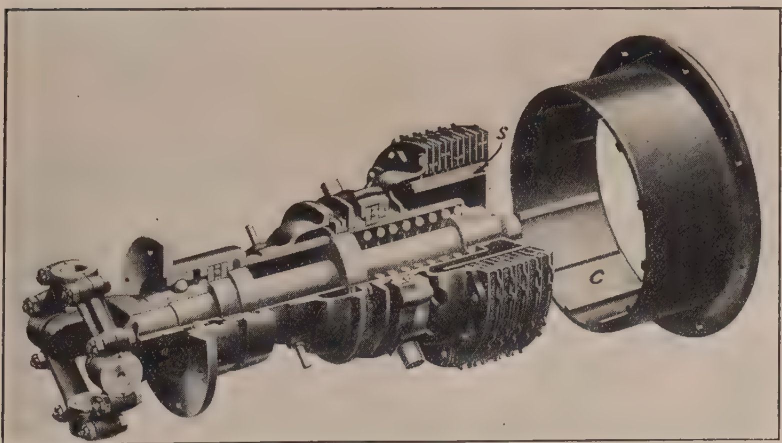

Fig. 15. Packard multiple-disc dry-plate clutch.

is especially useful with clutches having a high inertia. The clutch brake is made automatic and comes into action by pressing the clutch pedal slightly lower than necessary for disengaging the clutch, hence its use is optional with the driver. It is useful when shifting from a lower gear to a higher, i. e., when the engine rotates at a higher speed than the shaft to be meshed.

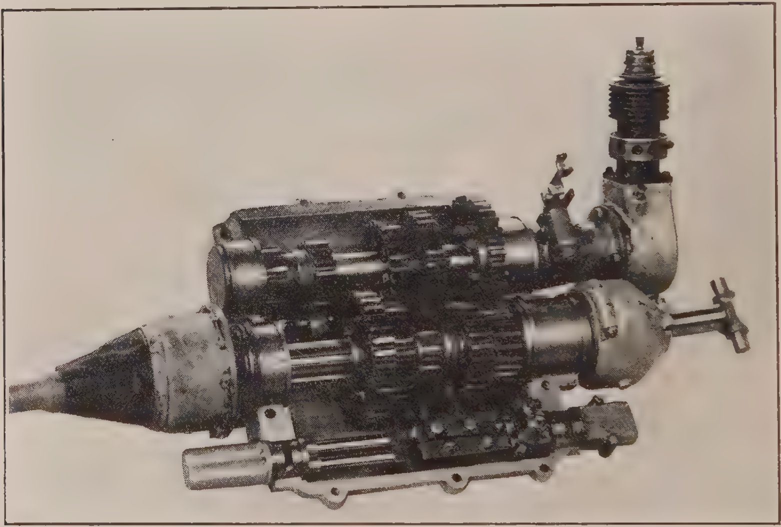

Fig. 16. Pierce-Arrow. Transmission.

TRANSMISSION.

There is a growing tendency to combine the transmission housing with the engine in a unit power plant, as seen from Figs. 1 and 3. About one half of the models are now so equipped, and, no doubt, practice will continue in this direction. The amid-ship location of the gear box, i. e., behind the clutch, is being abandoned rapidly. In the unit power plant, where the gear box is combined with the crank case of the engine, the advantage is the rigidity, maintaining the engine and gear box bearings in perfect alignment. It also lends itself especially well to the three-point support upon the frame, thus eliminating the stresses upon engine and gear box due to distortions of the frame.

In the unit power plant, a large amount of work is saved, and by using the center control—which is now the standard on 80% of the models—the control levers and pedals can be mounted directly on the housing of the power plant, thus eliminating a number of levers, shafts, etc. Another advantage is the accessibility of the gear box, it being directly below the front-seat floor-boards, whereas, in the amid-ship location the gear box is located further back.

The trouble with having the gear box located a small distance behind the motor is that when the frame is distorted slightly or sags the bearings of the engine and gear box get

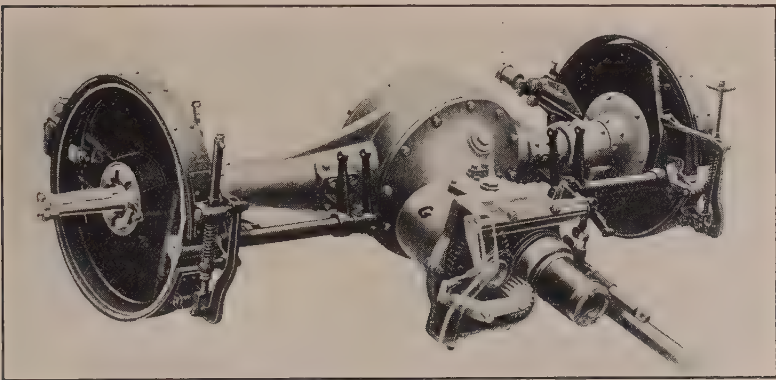

Fig. 17. Packard. Transmission housing attached to rear axle.

out of alignment; to overcome this defect, the universal or sliding joint has been made use of between the engine and the gear box, as seen from Fig. 16 (Pierce-Arrow). Note the compactness of the housing and the solidity of the shafts and gears. In Fig. 14 the gears and the clutch are in one housing. Here the sliding jaw-clutch, "j", connects the clutch with the engine.

Another system employed by several prominent makers is the gear box attached to the rear axle and combined with the driving-gear housing. While the unsprung weight on the rear axle is thereby increased, this defect is largely overcome by making the rear construction very light in weight. Fig. 17 (Packard) shows the gear housing, "G", attached to the rear-

axle construction. In both the unit power plant and the transmission-axle construction the propeller shaft can be made longer, thus reducing the angle between the engine shaft and the propeller shaft, thereby lessening the stresses created by harmonic speed fluctuations.

Fig. 17A (Ford) shows the planetary type of transmission, which is used in a successful small car. The different sets of gears are brought into action by stopping the revolution of the parts which support the gears. By means of the bands "a" and "b" (similar to brake bands) the rotation of the different parts is stopped; "c" is the multiple disc clutch, operating in oil. In the planetary type of transmission the gears are always in mesh.

The four speed transmission is losing ground, and the

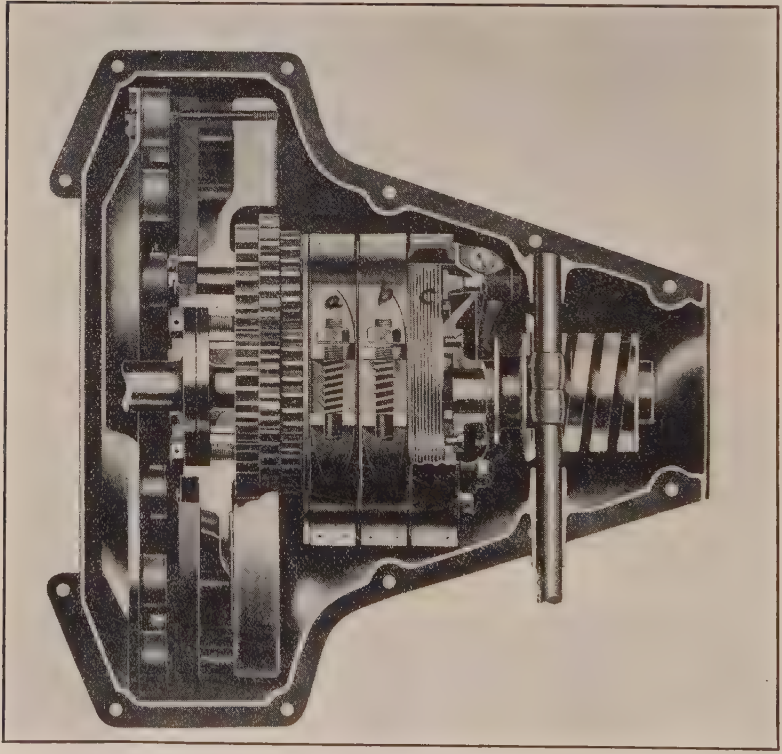

Fig. 17-A. Ford. Planetary type of transmission with clutch.

three speed forward and one reverse is becoming standard; no doubt the flexibility of the six-cylinder engine is largely responsible for this, as the car can be run very slowly on the high gear. The gears themselves have been improved by better materials and wider teeth, thereby increasing their life. By cutting the teeth more accurately, the noise has been largely eliminated; and by employing shorter shafts in the gear box, for the purpose of increasing the stiffness and to prevent shafts from getting out of alignment, the throw of the gear shift levers has been reduced.

FINAL DRIVE.

The spiral bevel-drive is rapidly being taken up by manufacturers; its efficiency is almost the same as the ordinary straight bevel gear, with the added advantage of silent running. The spiral or helical bevel does not require careful adjustment to make its running silent, due to the gradual engagement of the teeth—i. e., the teeth begin to come into engagement at one end first, the contact changing from one end of the tooth to the other by the time the next pair of teeth come into contact; in this manner a much smoother action is obtained than with ordinary spur gears. There are at least two helical teeth in partial mesh all the time. Fig. 18 (Franklin) shows the drive from the drive shaft to the rear axle by means of the spiral bevel-drive. The housing contains also the differential gears, as seen from the cut-open section. However, at the present time, the straight bevel is still used in a majority of the models. Fig. 19 (Maxwell) shows the bevel drive, with the drive shaft "a" and axle shafts "c" and "d" complete in the housing, while "e", "f" and "g" show the drive shaft and axle shafts removed, disclosing the details.

It is largely due to automobile construction that the great strides have been made in the perfect cutting of bevel gears, for in order to avoid noise and breakage, it was expedient that the teeth be cut to the correct contour. Helical bevel gears are somewhat stronger for a given size than plain spur gears. For the reasons mentioned above—i. e., greater strength, with the advantage of silent running—no doubt their adoption on a larger scale in the future is assured.

The most silent drive of all is the worm-gear drive. This can be made more compact than the bevel gear, and is especially useful where large reductions are required. In pleasure cars,

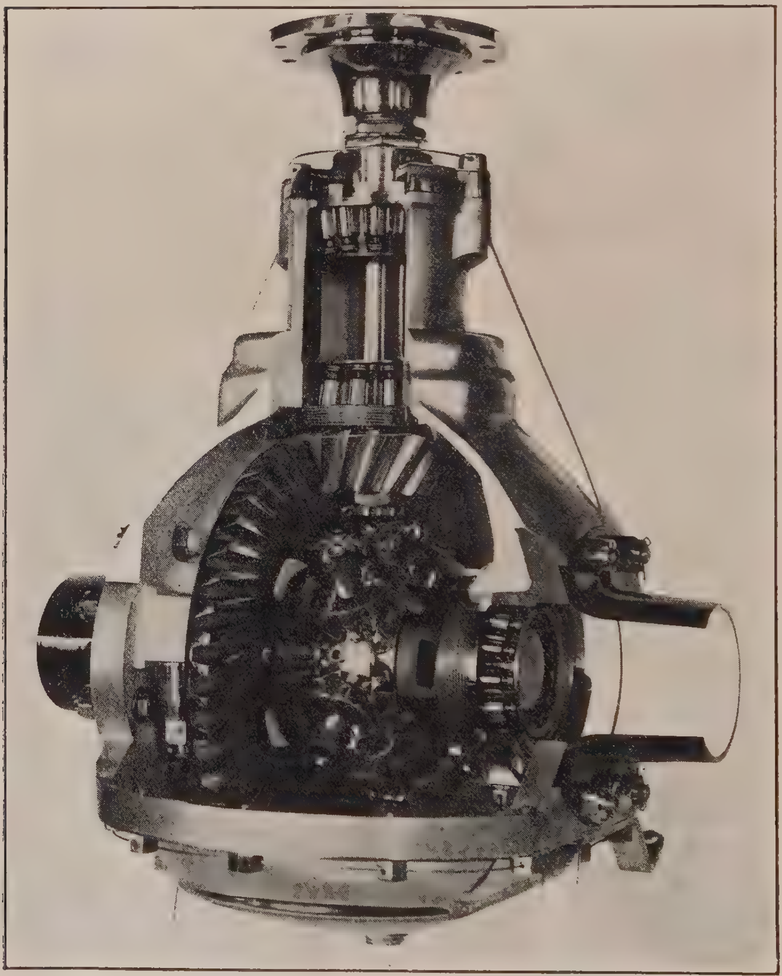

Fig. 18. Franklin spiral bevel drive and differential gear.

they are only used in a few instances at present, yet on account of their efficiency and durability (as they are less liable to sudden breakage than the spur gear), it is a question whether they will not be used to a large extent in the future.

With worm gears the efficiency is above 95%, and where conditions, like angles, etc., are favorable, more than 99% has been obtained. In the "hour glass" or Hindley worm gears, a film of oil always separates the teeth, and hence eliminates contact between them. The worm wheels are frequently made

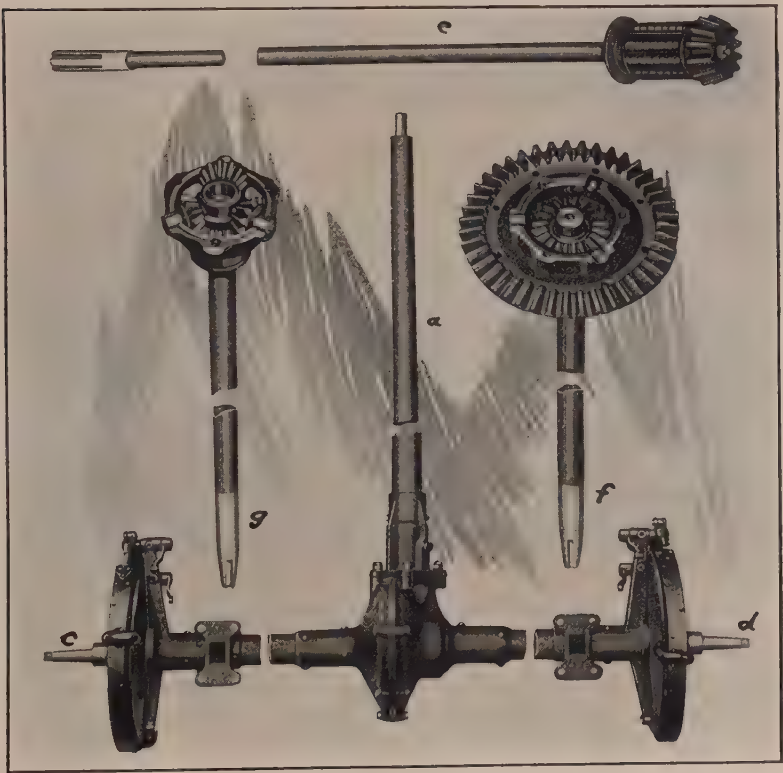

Fig. 19. Maxwell straight bevel drive and rear-axle construction.

of special hard bronze, while the worms are made of hard steel.

Fig. 20 (Willys Knight) shows this construction used by a well known manufacturer. The shaft, with the worm, is here underneath the worm wheel, while in some the shaft is above the wheel.

REAR AXLES.

In almost all the rear axles on the market, the differential is supported directly on bearings, and the inner end of the drive shaft floats in the differential. In most models, the outer end of the shaft is connected to the wheel simply through a jaw clutch, i. e., it is floating in the wheel as well as in the differential. This floating type of axle is employed in over 55% of the models. The semi-floating type—i. e., where the outer end of the axle has bearings—is used in about 25% of the models. The lower priced car, as a rule, has the semi-floating type on account of its simplicity and its lightness for a given strength. In the full-floating axle there is a greater strain laterally against the housing of the bearing. As each

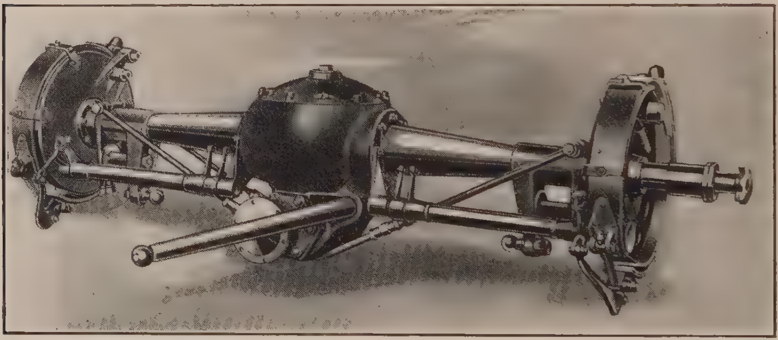

Fig. 20. Willys-Knight worm-gear drive and rear axle.

wheel is mounted on two bearings (sometimes on one only) at the end of the axle housing, only torsional driving strains are taken up by the axle shaft.

In the three-quarter floating axle where the wheel is mounted on a single bearing on the axle housing and is rigidly attached to the axle, either by a key or flange connection, there is no dead load resting on the axle, yet at the same time the lateral strains (for instance, when skidding) are reduced. In this type the axle is held in place either by the wheel bearing or by a lock in the axle housing or in the differential.

The three-quarter floating axle came into use about two years ago, and has been steadily gaining—being now used on about 20% of the models. This type is cheaper to manufacture

than the full-floating axle and allows a larger bearing surface for the rear wheels.

The pressed-steel construction of rear-axle housing may be made lighter for a given strength than the built-up form (usually constructed with tubing and castings), and is common practice with the floating type. While the dies for producing pressed-steel axle housings are expensive, the tendency to purchase such axles from axle builders has, no doubt, largely contributed to this design. The built-up axle, however, is more adaptable to use with the enclosed propeller shaft than with

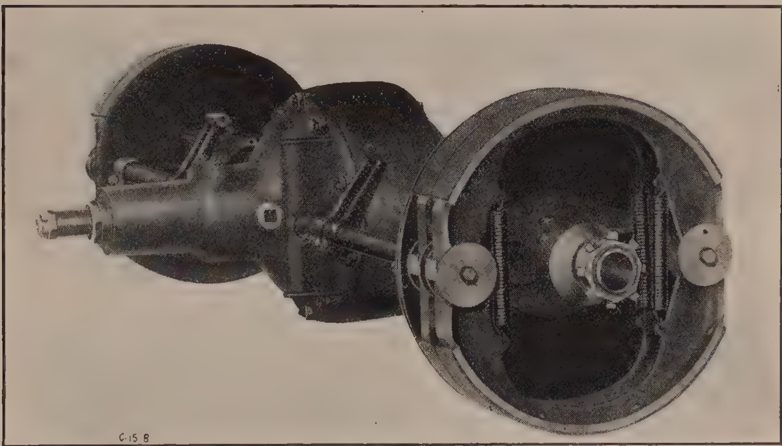

Fig. 21. Chandler pressed-steel rear-axle construction and double expanding brakes.

the pressed axle. Fig. 21 (Chandler) shows a full-floating, pressed-steel axle, and in Fig. 22 (Pierce-Arrow) is seen the built-up type, semi-floating construction of a well known make.

AXLE BEARINGS.

Practice for front wheels favors the tapered roller-bearing. Fig. 23 (Franklin) shows the standard on about 45% of the models, while the adjustable ball-bearings claim also many adherents. Rear wheels and the differential are usually provided with annular bearings and tapered rollers; flexible roller-bearings are also used here to some extent. Good examples of the latter are seen in Figs. 24 (Ford) and 25 (Maxwell) both well-known low-priced cars.

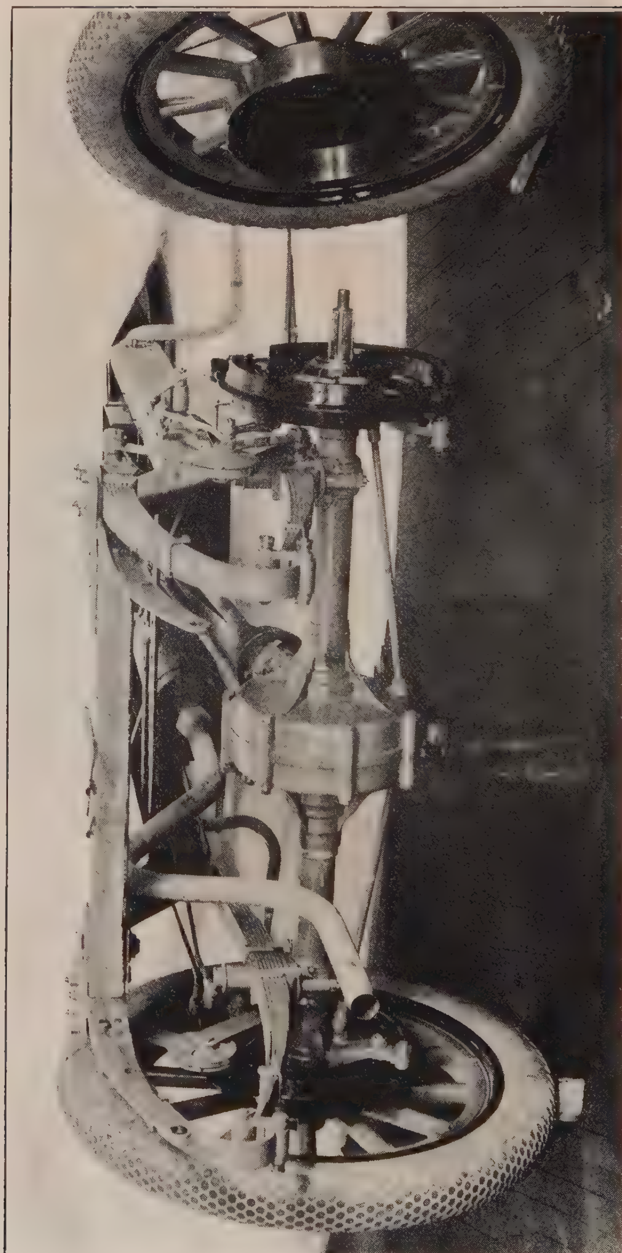

Fig. 22. Pierce-Arrow built-up type semi-floating axle.

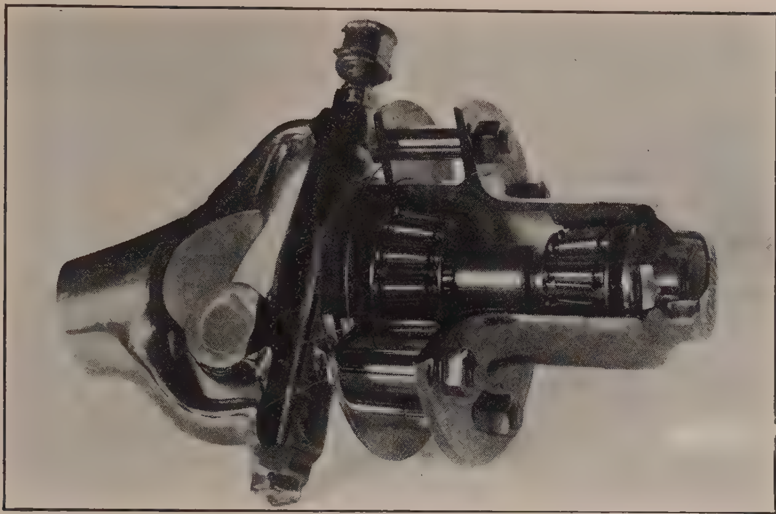

Fig. 23. Franklin front-wheel bearing.

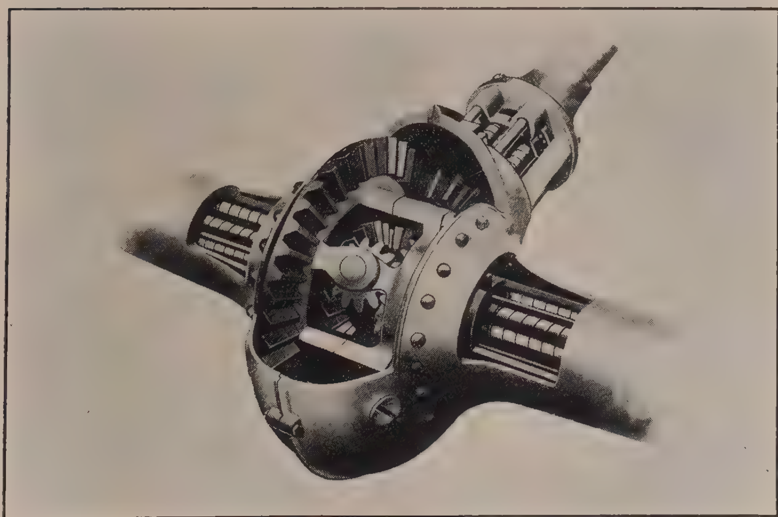

Fig. 24. Ford rear axle, showing flexible roller bearings.

Fig. 25. Maxwell rear construction, showing tapered roller bearings.

FRONT AXLES AND STEERING MECHANISM.

In Fig. 26 (Pierce-Arrow) is seen the I-beam front axle construction and the usual steering mechanism. Fig. 27 (Franklin) shows the worm-and-sector type, and Fig. 28 (Winton) the worm-and-nut steering gear. In the latter, a larger surface area is engaged, hence it is conducive to longer wear without the great amount of play so noticeable in many cars after being in service some time. Of course, where means are provided for adjustment, this defect can be overcome. In the worm-and-sector, the power employed for steering is transmitted through

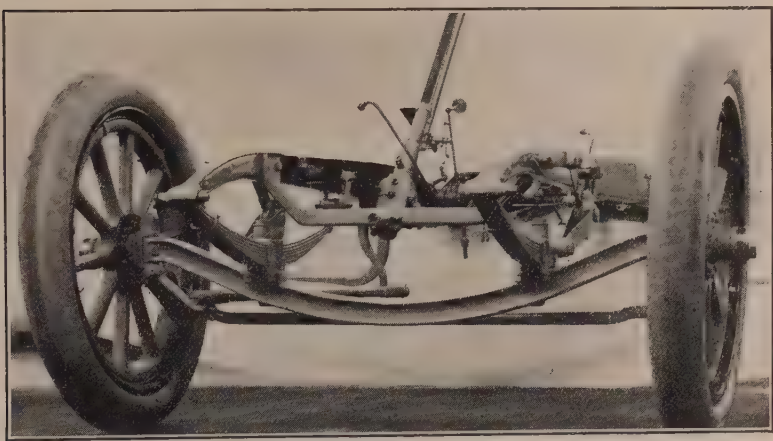

Fig. 26. Pierce-Arrow front I-beam axle construction.

a comparatively small contact area and would, therefore, cause more rapid wear; yet, as this has been the standard on many first-class cars for a number of years, it is evidently giving satisfaction.

TORQUE AND THRUST.

The most radical departure from previous models has been the adoption of the "Hotchkiss" drive, in which the rear axle is connected with the frame through the chassis springs only, making the latter perform the functions of torque and thrust. Heretofore, spring makers have objected to this construction on the ground that it subjects the springs to unnecessary

strains, but practice has shown the method to permit a slight yielding of the rear axle when starting and braking, by a certain amount of flexure in the springs, thus reducing the stresses on the transmission members. It seems fair to predict the more extensive adoption of the "Hotchkiss" drive by manufacturers. Over 17% of the models now employ this system, while about one half take the thrust through the springs,

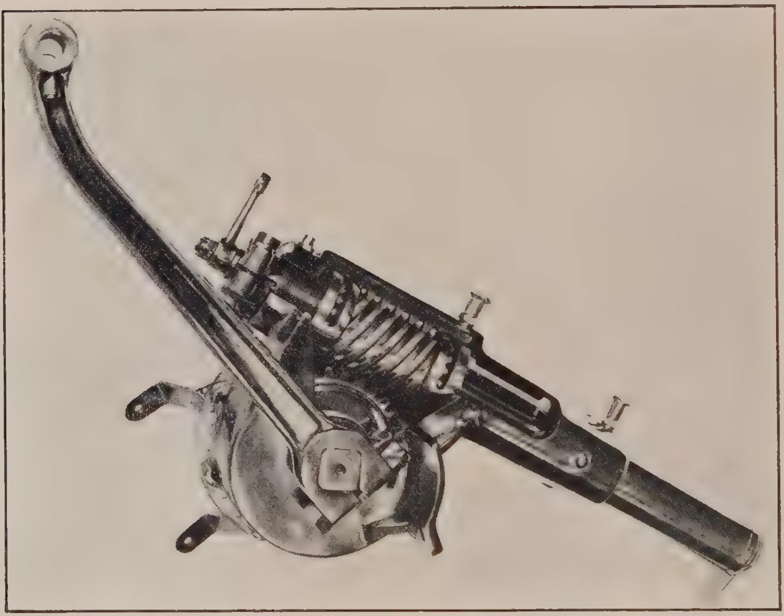

Fig. 27. Franklin worm-and-sector steering gear.

and others through the radius rod using the spring for taking the torque. Fig. 25 shows how elimination of torque and thrust rods simplifies the rear construction. In the "Hotchkiss" drive the springs are rigidly attached to the rear axle, while the front end of the spring is secured to the frame with a proportionately large bolt through which the drive is transmitted. Manufacturers using the "Hotchkiss" drive claim that it is quieter, more flexible, and that the car holds the road better; it avoids the road shocks, which are transmitted through stiff

torque members from the axle to the frame. The makers who drive through the springs, and employ other torque members, claim that they are not sacrificing flexibility in driving, while

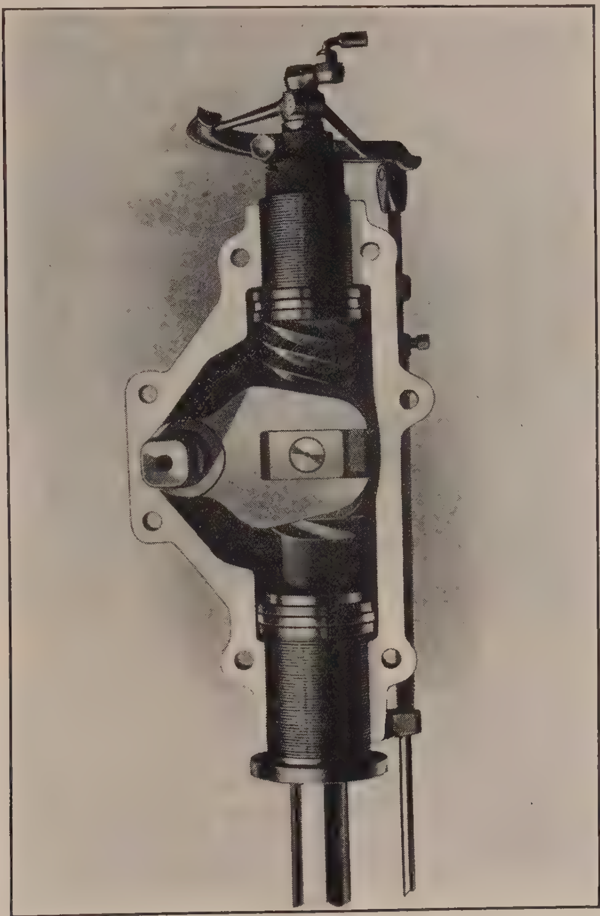

Fig. 28. Winton worm-and-nut steering gear.

eliminating a certain side sway and other strains prevalent when the springs perform the functions of the torque. Radius rods are apt to rattle, yet they are incorporated in about 20% of the models.

UNIVERSAL JOINTS.

In the "Hotchkiss" drive, as well as with separate torque members, two universal joints in the propeller shaft are required; this may account for the increased number of models provided with them. By having the engine shaft in line, or almost in alignment, with the differential, there is very little friction loss in the universal joint. When using two universal

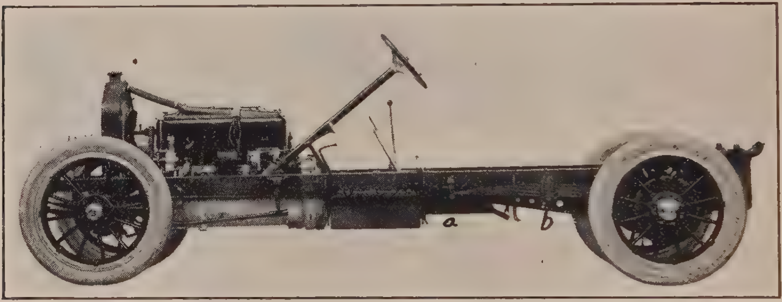

Fig. 29. National Chassis—see Cantilever Spring.

joints, there is less strain in the shafts, and practice has also shown that there is less friction loss for a given drive out of alignment than with one universal joint.

SPRINGS.

The tendency at present is to so design the frame and spring suspension that the rear springs are situated very close to the wheels. In some instances, the frame is wide at the rear and directly over the springs. Semi-elliptic springs are standard for front suspension (see Fig. 26) although a few manufacturers employ the full elliptics. The rear spring most widely used is the three-quarter elliptic (see Fig. 25), while semi-elliptic and platform springs are losing ground. The cantilever spring has recently made its appearance and is now applied to over 7% of the models. This spring (Fig. 29, National) is attached to the frame at one end, "a", and supported in the middle, "b", the other end being attached to the axle. The advantages of this type are the smaller unsprung weight and the reduced manufacturing cost for a given amount of flexibil-

ity. Another advantage is the absence of sharp rebounds, and a greater deflection for a given load and length of spring; it also obviates the cut in the body required with the three-quarter elliptic spring. When the cantilever spring takes the driving strain, the main leaf is usually stiffened—being stronger sidewise, it eliminates a great deal of side sway. When torque rods are employed, the main leaf may be made lighter, as the starting, braking and torque are transmitted through the torque rods. Since there is more metal in the line to the thrust, they are especially suitable for taking the thrust, and not quite as efficient in taking the torque. Fig. 30 (Ford) shows the front

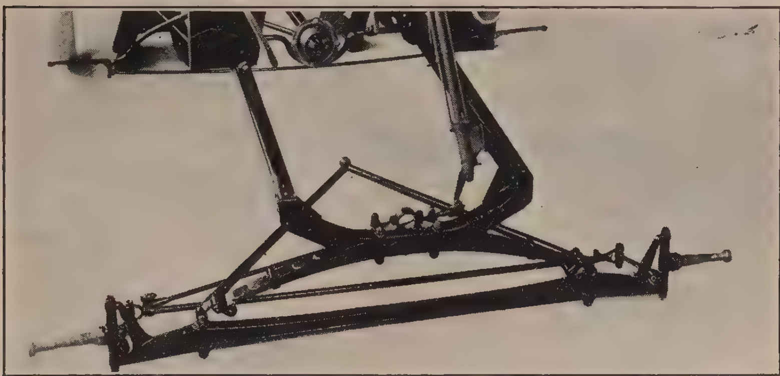

Fig. 30. Ford. Front axle construction.

suspension of a well known small car, the rear being similar in construction; and as there are many thousands of these cars in service that are giving satisfaction, this suspension for small cars must be considered very satisfactory.

CHASSIS FRAME.

A tendency of design is to have the chassis frame wider at the rear and narrower in front, for the reason that it allows more space to support a wider body in the rear while a narrower front will enable the car to turn in a shorter radius. A more recent development is to make the longitudinal bars of the frame only parallel over the front spring and near the rear spring, and to have them tapered from behind the front to the

rear springs. (See Fig. 31, Hudson.) A certain amount of material is gained in this manner, as no heavy reinforcement or sudden offset is necessary to the frame. By widening the frame in the rear, it is also possible to place the springs directly underneath the frame, as shown in this figure. Some manufacturers have the sides of the frame straight over the whole length, but tapered from the front to the rear.

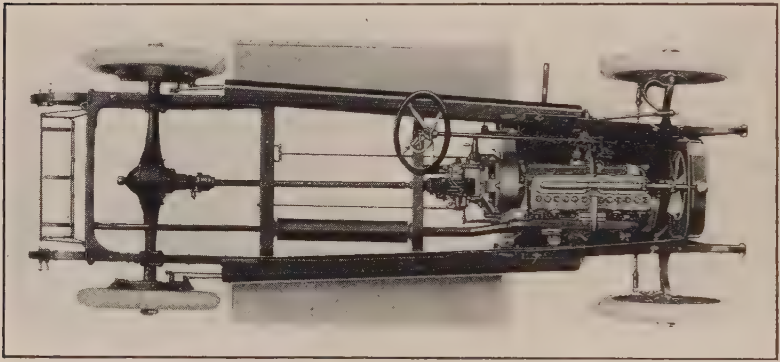

Fig. 31. Hudson Chassis. Plan view.

WHEELS.

The standard in this country is the wooden wheel. Wire wheels have been in use on a few cars and have been found to give satisfaction, but they do not possess the advantages usually claimed for them. Tests made by the Automobile Club of America* on the effects of the wear of tires on wire and wooden wheels have shown the average life on the wooden wheel to be 8,076 miles, while the average on wire wheels was only 6,470 miles. These tests were made under identical conditions at the same time, and ought to be satisfactory evidence that wire wheels are not, under any circumstances, superior to wooden wheels, as far as life of tire is concerned. Tests made at the University of Michigan† showed in the matter of strength, in the ability to "give" under a shock, and in the power of re-

* Bulletin of the Automobile Club of America (Testing Laboratory), August, 1914.

† Society of Automobile Engineers, "Wood Wheels vs. Wire Wheels", R. B. Mudge, January, 1915.

covery the marked superiority of the wooden wheel. Other objections against the wire wheel are: its reduced life, increased cost of upkeep, and increased first cost over the wooden wheel.

IGNITION.

The magneto has been almost universally employed for ignition until within the last year, when a number of manufacturers have abandoned its use. The storage battery with an electric generator for lighting, starting, as well as for the ignition has been widely adopted, and the tendency seems to indicate the further adoption of this type in the near future. While at present about 55% of the models continue to use the magneto, it is believed that in next year's models they will be in the minority. Where self-starters are installed, the cranking motor rotates the engine with sufficient speed to start directly on the magneto, thus avoiding the necessity of a battery. Dry cells, however, are frequently used as an emergency source for ignition. Another tendency is the adoption of the single system of ignition; where the single battery system is used, it has been adopted because it was considered needless to have two current generating devices. The generator furnishes the current to the battery, which in turn supplies the crank motor, ignition and electric lights. Single ignition is now used on about 56% of the models, while dual ignition is employed on only 36%.

With a magneto, a battery is often employed, as it will start the engine at slower speeds (it is generally used with cars having no self-starters) when cranking by hand. The modern high-tensioned magneto has been developed to a high degree of perfection, and is retained by a number of manufacturers on account of its reliable ignition current, for which is claimed that, at high speeds, it will add to the power of the engine. Nevertheless, it is thought that it will be superseded, for with electric starting and lighting systems where a current generator is employed it is needless to have another generator for the spark. With the latter type (starting and lighting generator) a battery is employed to supply current to a single spark interrupter, and, of course, in this case the spark does not vary in intensity with the speed of the engine. By using the magneto

type of interrupter, the ignition lag is reduced to a minimum, thus overcoming the objection heretofore made against battery ignition, where the spark levers must be manipulated continually. Another tendency is the employment of automatic spark timing devices, applicable to magnetos, to interrupters on generators, or to separate distributing devices. Where they are employed hand control may be used in connection therewith. About one-quarter of the models are provided with automatic spark-timing devices.

LIGHTING AND STARTING.

In some of the lighting and starting systems on the market, a single dynamo acts either as a generator or motor, while in others, the generator and a separate motor are used. The first type is known as the single-unit, and the latter, the double-

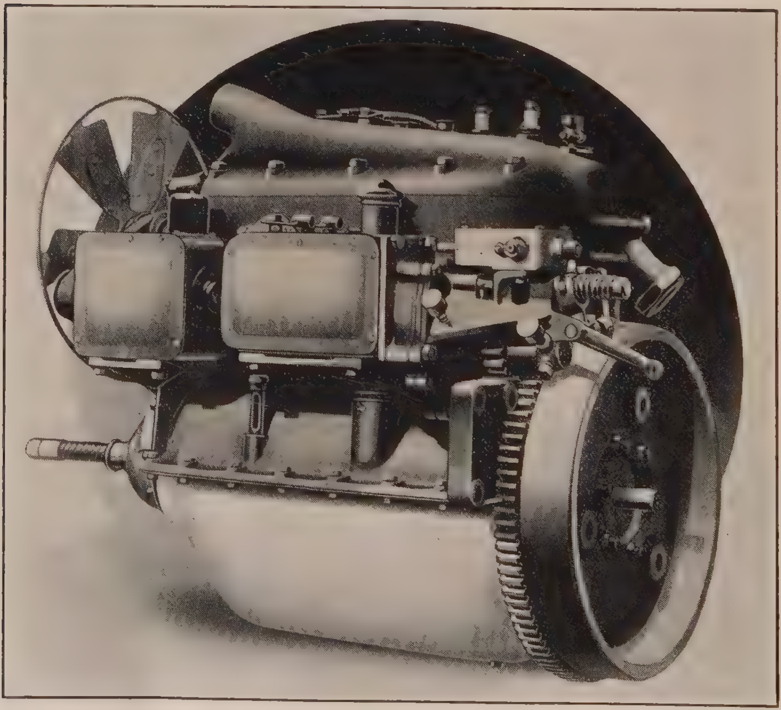

Fig. 32. Maxwell engine, showing self-starting connection to fly-wheel.

unit system. In the former, one driving connection only is required, and it is lighter in weight, as fewer parts are necessary and they require less space than the double-unit system. In the latter, however, a higher efficiency is obtained, since the generator as well as the motor can be designed specifically for the work they have to do. As is well known, for charging storage batteries, the dynamo must be shunt wound, which system is also more favorable for obtaining a better voltage control, and any accidental change in the battery polarity would not change the polarity of the dynamo. On the other hand, to obtain the greatest torque at slow speeds (when used for starting the engine), a series wound motor is by far the most efficient. In some of the single-unit systems, the machine is compound wound; while in others, two armature windings and two commutators are employed—for generating the current and using it as a motor, respectively. One of the latest designs for electric starting is the double-deck systems, where the generator and motor are placed above each other with their shafts connected by gears of the type permitting the transmission of power in one direction only. This type is very compact and has the further advantage of using only one driving connection to the engine.

It is customary to connect the starting motor to the engine fly-wheel directly through gearing, as shown in Fig. 32 (Maxwell). Here a separate generator is employed, hence the gears are only thrown into engagement when the motor is started; this is done by pressing on a plunger pedal, which starts the electric motor and also engages the starter pinion with fly-wheel gearing.

Note:—All discussion pertaining to motor vehicles will be found at the end of Paper No. 132.

Paper No. 131

MOTOR VEHICLES; UTILITY TYPE.

By

ARTHUR J. SLADE,
Mem. Am. Soc. M. E., Mem. Soc. of Auto Engrs., Assoc. A. I. E. E.
New York, N. Y., U. S. A.

INTRODUCTION.

Motor vehicles of the Utility type are known according to current American nomenclature as "Commercial Motor Cars" and are defined as follows:

"Self-propelled vehicles designed to be operated without rails, for the primary purpose of transporting materials, products, passengers or apparatus, especially for business purposes or for hire, profit, emergency work or special utility service; as distinguished from private personal use by the owner or renter for enjoyment or convenience."

In accordance with the suggestions of the Committee, this paper will present results of the author's observation of the development, during the past decade, of the general types of commercial motor cars which have to any marked extent become standardized, giving the present status as to general features of design and application, and the tendencies of future development. Some consideration will also be given to types of vehicles, and their application, which while not as yet in extended use, seem to have such possibilities of usefulness as to indicate that within the next decade they will have become standardized to an extent at least as great as the types developed in the past.

The development commenced at about the same time in the United States, in England and on the continent of Europe, but in these three parts of the world the work was generally carried on along radically divergent lines.

In the United States most of the experimentation and development work was in connection with storage-battery electric vehicles; in England, with steam lorries; and on the continent of Europe, with gasolene or petrol trucks. It seems impossible

to offer a logical explanation for this variance in the direction of the inventors' or manufacturers' efforts, but at any rate in the United States the storage battery electric truck was first developed to its highest degree, as was the steam lorry in England and the gasolene truck on the European continent. The American electric may now be considered the universal standard design for this type of vehicle, though it has been developed to some extent in Germany, especially in connection with taxicab operation, and to a limited extent in England.

After the experimental stage of the electric had passed and the industry was becoming firmly founded, the development of steam and gasolene vehicles was taken up by American engineers and manufacturers.

The success which seems to have attended the use of steam lorries in England, especially in connection with trailers, was not duplicated in this country, and after experiments with the English type of steamer, as well as with several types originated here, using both coal and gasolene or kerosene for fuel, the steamer disappeared from sight.

Early experimenters with steam trucks have offered the explanation that among the causes of failure was the loosening of pipe connections due to vibration caused by uneven street and road surfaces, excessive leakage resulting. Also that competent men could not be had at a reasonable rate of wages who would act as fireman, engine man and driver. Further, in the cities where these vehicles were tried, serious objection was offered to their noise, exhaust of smoke and steam, and the unusually cumbersome appearance. From the operating point of view, they did not show economy compared with other types of self-propelled vehicles.

The lack of success in adapting to American uses this foreign type of vehicle was not the case, however, with the vehicle propelled by an internal combustion engine using liquid fuels. Spasmodic and usually unsuccessful efforts to develop gasolene motor trucks from gasolene passenger or pleasure vehicles (which latter were being developed here at practically the same time that they were abroad) were made from time to time, especially during several years previous to 1908. It was supposed

that component parts intended primarily for use on pleasure cars would prove adequate for commercial vehicle use and that the manufacture of the latter could be carried on as an adjunct to the former. This idea soon proved fallacious and the successful gasolene motor trucks now produced in this country are largely due to the influence of designs of similar machines produced in Europe, especially in Switzerland. France and Germany. More recently a notable English design has had a marked influence. Within the last five years, especially, American gasolene trucks have reached a position where in design, material and workmanship they are the equal, if not the superior, of the foreign-built machines, and for the road conditions existing in this country, in all respects superior. This is due largely to more powerful engines and greater road clearance than is usual abroad, but these requirements were rendered necessary on account of the imperfect road surfaces and excessive grades found generally outside of cities or largely built-up communities, and frequently even within these localities.

The two types of vehicles, therefore, which have approached some degree of standardization, namely, the storage battery electric and the internal-combustion engine-driven, will be first considered, and special applications of same or combination of both will be referred to later.

Each of these types of machines has its own distinctive field of usefulness, and these fields to some extent overlap: the electric being essentially a machine for operation in cities or where road surfaces are of good quality and where the mileage is limited by number and time of stops, congestion of traffic or speed-limit ordinances; the gasolene truck on the other hand being specially suitable for use either in city or country, where road surfaces are bad or operating conditions require long mileage at higher rates of speed than are possible with the electric.

ELECTRIC TRUCKS.

First considering the storage-battery electric, vehicles ranging from one- to five-tons capacity were all developed at practically the same time. Although the general external ap-

pearance of many machines built more than ten years ago and still in operation does not differ radically from those now generally being built, the details of design and construction have undergone radical changes.

General Features.

Early machines had wheels of the type ordinarily used on horse-drawn vehicles, with wooden hubs and plain spindle or brass bushed bearings, while the modern vehicles have wheels of the artillery type, with cast steel or malleable iron hubs and spindle bearings of the annular ball or adjustable conical roller

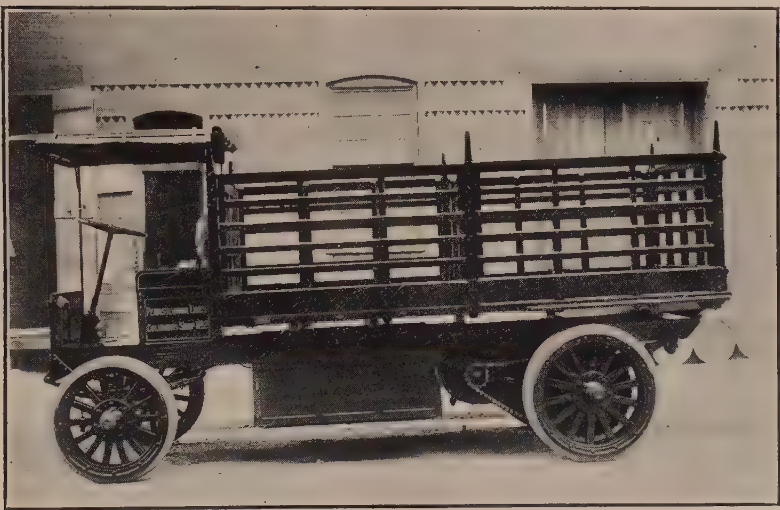

Fig. 1. Atlantic 3½-Ton Storage-Battery Electric Truck.

type. Thus friction is reduced and the operating efficiency of the vehicle substantially increased. The springs were of the full elliptic or semi-elliptic type, fastened at one end and with sliding bearing seat at the other end, the torsion and driving efforts being taken by the springs or by structural members, known as pedestals, consisting of guides permitting vertical sliding movement of the axle but relieving the springs of the driving effort. Modern spring construction consists of semi-elliptic springs suspended by shackles at each end (except in the case of front springs, which are shackled at rear end only) and the driving stresses are taken up by radius rods having uni-

versal connections permitting freedom of movement of axles with reference to truck frame. The quality and design of springs, especially as relating to camber, deflection, material, number of leaves and heat treatment, have also undergone radical changes. The improvement in spring design, construction and suspension is an important factor contributing to economy of operation and maintenance. The increased flexibility of springs relieves the vehicle of much vibration, effecting greater operating efficiency, reduced precipitation of active material of battery plates, less impact and abrasion of tires, and very much less actual breakage of the springs themselves or the parts by which they are mounted or suspended.

Motors.

The early electric motors, while of the present series-wound type, had their armatures mounted on plain bearings, while they are now mounted on annular ball bearings. They drove the rear wheels through internal or external rack and pinion gears, while the present drive is generally by silent chain, enclosed and lubricated, from motor to jack-shaft, and thence by roller chains from jack-shaft sprockets to driving wheel sprockets. One motor is used instead of two, as formerly, which necessitates the use of a differential; but the combined losses of the chain reductions, differential and jack-shaft are materially less than in the case of the former double-motor drive. There are at the present time individual instances of the double-motor drive through gear and pinion reduction, and also cases of shaft drive from motor to jack-shaft with bevel gear and pinion which are highly efficient, and further developments may be expected along the lines of reduction in number of parts in the final drive, with increased transmission efficiency.

In order to reduce the weight of the vehicle and its current consumption, remarkable strides have been made in the development of vehicle storage batteries, resulting in the increase of the watt-hour capacity for a given weight, and at the same time reducing the battery maintenance expense. These modern batteries, in connection with the refinements in the design of the vehicles, have within the last ten years doubled the mileage capacity for a given current consumption.

Contributing also to this increase in efficiency has been a change in weight distribution between front steering wheels and the rear driving wheels from approximately 50% front and 50% rear to 40% front and 60% rear, and in some cases 30% front and 70% rear. At the present time it may be stated with confidence that with adequate wheel bearings a maximum load on the rear driving wheels contributes to the maximum efficiency of the vehicle, the only weight desirable on the front wheels being that necessary to give efficient steering effect under varying road grades.

Wheels.

An increase in the diameter of the driving wheels also favorably affects the operating efficiency, and while 36 in. diameter tires are still usual on most electric trucks, some machines have wheels of 40 in. diameter, and their use has indicated that the increase in operating efficiency and in tire mileage is practically proportional to the increase in tire diameter.

In the reduction of chassis weight the use of alloy steels and the elimination of all possible unnecessary parts have been large contributing factors.

Convenience of operation, which implies safer operation, and which in practical service effects operating economies, has been furthered by the use of irreversible steering gears, double sets of brakes and more comfortable drivers' seats, with adequate protection against the weather.

Greater protection of batteries against the admission of foreign substances, by means of removable, watertight battery covers, and means for more easily removing batteries, either complete or in individual trays, are subjects now receiving careful attention; and in the not distant future standardization of battery cradles and battery assemblies may be expected, enabling frequent and quick interchange of batteries when desirable, thus enabling a truck to be equipped successively by several batteries during a single working day, if necessary, thereby rendering the radius of operation and the variety of application of service of the electric vehicle much greater.

Final Drive.

In the smaller capacities of electric trucks, that is, less than one ton, the tendency is distinctly in the direction of the

shaft drive from a single motor through a bevel gear and pinion or a worm-and-wheel reduction mounted in a floating rear axle. The motor is in some cases suspended from the chassis frame, driving to the rear axle through a shaft having two universal joints. In other cases, the motor is mounted on a sub-frame integral with rear axle and pivotally suspended from chassis at forward end, thus eliminating universal joints. The extensive

Fig. 2. "Ward" Shaft-Driven Storage-Battery Electric Delivery Wagon.

use of light electric vehicles driven by chains is not likely to be continued.

Wiring.

The wiring from batteries to controller and thence to motors is, according to modern practice, enclosed in conduits, and is of much more liberal size than formerly, in order to reduce the voltage drop. Good modern practice calls for the following minimum size of wiring on the trucks of sizes specified: 1 ton No. 4, 2 ton No. 2, 3½ ton No. 1, 5 ton No. 0. Maximum sizes greatly exceed these. It is not uncommon to use No. 000 wiring on trucks having large batteries subjected to heavy current draw, especially the nickel-alkaline type. Also where

high rate charging is resorted to. The controllers nearly universally adopted are provided with four forward speeds and two reverse speeds. The driving motors being of the series-wound type, the connections are generally as follows: First speed forward, fields in series through double resistance in series with armature. Second speed forward, fields in series with armature shunted around resistance (running speed). Third speed forward, fields in series with armature on half of resistance shunted. Fourth speed forward, fields in parallel and in series with armature without resistance (running speed). Occasionally a fifth speed is added, weakening the fields and thereby causing an increased armature speed and a correspondingly increased speed of the vehicle. It is questionable whether this fifth speed is desirable, as under heavy loads, with increased armature current, the higher speed is not maintained and the efficiency of the vehicle is greatly reduced. Recent tests under the observation of the author have indicated that on the fifth speed of controller over 20% increased current consumption results in less than 10% increase in speed. Bearing in mind that a high running speed in miles per hour is not of any material advantage to the electric truck under conditions of proper use, it seems conclusive that in the hands of the ordinary operator the four-speed controller is preferable.

Batteries:

Storage batteries for electric trucks are of two types, the lead-acid and the nickel-alkaline. The latter has been used very extensively in recent years, though the preponderance of batteries in use is of the former type. The voltage of the lead battery is approximately two volts per cell and of the nickel battery one volt per cell, these figures being approximate only, as the voltage curves of the two types between full capacity and discharge are of a widely different form.

Normal sizes of batteries which will give 40 to 50 miles operation in well-designed and -built electric trucks are as follows:

Lead-Acid	Capacity	Size of Vehicle
13 plate	190 amp-hours	1 ton truck
17 "	215 " "	2 " "
21 "	270 " "	3½ " "
25 "	324 " "	5 " "

Nickel-Alkaline	Capacity	Size of Vehicle
A 6	225 amp-hours	1 ton truck
A 8	300 " "	2 " "
A 10	375 " "	3½ " "
A 12	450 " "	5 " "

The standard number of cells in the lead-acid battery is not yet agreed upon, 42, 44 and 48 being extensively used. On account of the difficulty in charging batteries of more than 42 cells in certain localities, due to lack of necessary voltage on central station mains, 42 cells will probably be adopted in the near future. This number lends itself well to battery and tray assemblies. The standard number of cells in the nickel-alkaline battery is 60.

Standardization of battery assemblies is under consideration by the Society of Automobile Engineers, and eventually a greater interchange of batteries than is now possible will be in effect.

Both types of batteries will undoubtedly be used indefinitely, and the motors to be operated by them, therefore, are designed to provide for windings which make it possible for the same frames to be used in either case. The leading manufacturers of automobile motors, while producing substantially identical machines, do not at present give them identical voltage ratings. On account of the form of the voltage curves of the batteries on discharge, opinions differ as to the proper motor voltage rating, and the motors for use on the nickel-alkaline batteries, therefore, are rated at 60 or 65 volts. For a similar reason the motors for use with lead-acid batteries are rated at 80 or 85 volts.

The following motor sizes are generally used on the sizes of trucks noted, the two voltages being for use with either lead-acid or nickel-iron-alkaline batteries:

1-ton and 2-ton Trucks—	
80 or 85 volts	28 amperes
60 " 65 "	40 "
3½-ton Truck—	
80 or 85 volts	40 amperes
60 " 65 "	60 "
5-ton Truck—	
80 or 85 volts	50 amperes
60 " 65 "	70 "

Speeds of electric trucks are generally as follows, assuming level, hard, smooth road surface and running on 4th controller speed:

1-ton	Light	12 miles per hour
	Loaded	10 " " "
2-ton	Light	11 " " "
	Loaded	9 " " "
3½-ton	Light	10 " " "
	Loaded	8 " " "
5-ton	Light	9 " " "
	Loaded	7 " " "

The current consumption of trucks of these capacities and speeds at full load should not exceed the following figures, and 10% lower consumption has been shown in certain carefully designed and constructed vehicles:

1-ton	75 watt-hours per ton mile
2-ton	70 " " " " "
3½-ton	60 " " " " "
5-ton	55 " " " " "

Tests should be made over a measured course, which need not exceed 1/8 or 1/4 mile, full speed having been attained at start of course, and the run being made in both directions, with a sufficient number of volt-meter, ammeter and stop-watch readings taken to insure practical elimination of errors in observation.

GASOLENE TRUCKS.

The earliest types produced in this country were modeled largely on the design of pleasure vehicles, using many of the same parts with the idea of making motor trucks an adjunct to the pleasure car. This plan was entirely unsuccessful, and only when the design of motor trucks was taken up as an entirely separate proposition from pleasure vehicle design were vehicles produced which gave satisfactory service; and, as previously stated, the influence of European design had a very large influence in the success of the American product.

In the earlier machines, efforts were made to use two-cycle engines, under the erroneous theory that motor-truck service in some respects resembled marine service, particularly in that the load and speed were uniform and constant in both cases, and therefore, that the type of engine suitable for boats would

be suitable for trucks. The necessity for wide ranges of load and speed in truck engines soon became apparent and the use of 2-cycle engines was short lived.

The number of cylinders also was a question upon which varying opinions were held, numerous machines being placed on the market having two-cylinder engines, but with one notable exception two-cylinder engines are of the past as far as motor-truck use is concerned. The present accepted practice is the four-cylinder four-cycle type. There seems to be no tendency to increase the number of cylinders above four.

The average cylinder diameters on the most generally used sizes of gas trucks are as follows:

½-ton	3½	inches
1-ton	4	"
2-ton	4¼	"
3- and 4-ton	4½	"
5- and 6-ton	4¾	"
7½-ton	5	"

Note: Statistics are compiled by trade publications periodically to indicate the trend of design from year to year, but as the averages are made up from all the models offered for a given year without any particular consideration of the number of each model actually manufactured, the figures and percentages are doubtless not exact, but certainly indicate the trend.

The stroke of truck engines has been gradually increasing, which in connection with their low running speed permits of a more economical and effective use of fuel, and a ratio of bore to stroke of 1 to 1 4/10 is not now excessive.

Engines in motor trucks being subjected to so much more severe service than those in pleasure vehicles, require more liberally designed parts, especially in connection with crankshaft and connecting-rod bearings. The requirements of a truck engine also vary from those of the pleasure-car engine, in that a well-sustained torque be had at all operating speeds and it has become general practice to limit the piston speed to 1000 ft. per minute, which is low as compared with pleasure car engines. Hence these engines are now designed for a rugged and substantial construction, with very liberal bearing surfaces, even though the weight is thereby increased, and are with few exceptions equipped with a speed governor of the centrifugal-

weight or fly-ball type, operating a throttle between carburetor and intake manifold. Governors of other types and methods of application are being developed, notably, one operated by the running speed of the vehicle rather than by the rotative speed of the engine, and further valuable development in connection with automatically controlling engine and truck speeds may be looked for.

Air cooling was also experimented with to some extent, and one make of light truck up to within the past year successfully used this type of cooling, but the present standard method is water cooling, preferably with pump circulation, though the thermo-syphon has its advocates. The latter method has the advantage of simplicity, but in service where the stopping, standing and starting of the vehicle is frequent there is less uniform temperature of the engine cylinders than in the case of pump circulation. The thermo-syphon finds its principal application in vehicles under one-ton capacity. Above that size its use is negligible.

The vibration to which a motor truck is subjected, due to its heavy weight and solid tires and necessarily stiff springs, has made necessary the development of a special type of truck radiator. In addition to the water capacity being increased approximately 50% over the capacity necessary on a pleasure vehicle of the same engine size, radiators must be protected against leakage due to connections being broken by vibration, and a cast metal frame with readily removable and replaceable core or group of tubes, all connected with bolts and gaskets, is now generally adopted instead of sheet-metal frames with soldered connections and suspended by springs to protect against vibration.

Clutches have not reached any degree of standardization, the three usual types being the leather-faced cone clutch, the multiple disc running in oil, the plates being of tempered steel, and the dry-plate clutch, consisting usually of plates of metal contacting with plates faced with non-burning fabric. The cone clutch is used on somewhat less than one half of the 1915 designs, the balance being equipped with some type of disc clutch. The simplicity of the cone is its marked advantage. In truck operation it is necessary that a certain amount of clutch

slipping be allowed for purposes of acceleration, so contact surfaces must be very liberal. Adequate surface can be provided in either design.

Transmission:

Although it is possible in the design of engine and clutch to use three-speed transmissions, and over 80% of the 1915 models are thus equipped, the use of four speeds operated selectively is considered preferable by some of the largest manufacturers for general service conditions, especially when the use of trailers or semi-trailers is contemplated. Although not extensively adopted, the individual clutch system is distinctly advantageous when it is considered that the average truck driver is not a skilled vehicle operator, and there is less likelihood of injuring jaw clutches through unskilled operation than is the case with sliding-gear transmissions, where greater operating skill is necessary.

Final Drive:

This subject is a source of continual and animated discussion among the truck designers and has been during the past decade. Generally the types may be narrowed down to shaft drive to the rear-axle unit direct, or shaft drive to a jack-shaft unit and thence by side chains to rear wheels. The latter, while it has distinct advantages and is found on fully 60% of the 1915 trucks of one ton and upward, is gradually becoming eliminated. The most generally used type of the direct-shaft drive is the worm and wheel with floating axle. Developed to its highest degree in England, it was successfully introduced in this country within the past 5 years, and very recently the manufacture of worm-drive axles has been taken up by axle builders who supply the motor truck trade, making it possible for assemblers and small truck builders to adopt this drive. 1915 trucks show 25% using this drive, the majority of 2-tons capacity and under.

The internal-gear drive, extensively used in France and Germany for many years, is now being introduced to some extent, as axle manufacturers are taking up its construction and it is impossible to predict which of these types will eventually become standardized; but it must be borne in mind that the more general use of trailers will require transmissions and drives

which will be reasonably efficient under heavy pressures of contact surfaces. One notable example of a shaft-drive axle not coming under the above two types is the double spur-gear reduction. This method has also been used successfully in at least one well-known English truck.

Brakes:

All gasolene machines have two sets of brakes, and it is a question still open to discussion as to whether one brake should be placed somewhere between the engine and axle and the

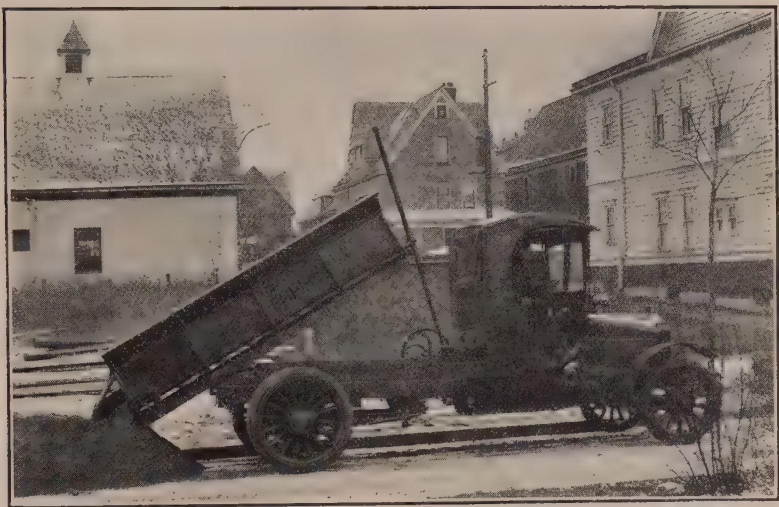

Fig. 3. "Pierce-Arrow" 5-Ton Worm-Driven Gasolene Truck; Hand Dump.

second on the rear wheels, or whether both brakes should be attached to the driving wheels of the vehicle.

Springs:

General practice is tending more and more to semi-elliptic springs, front and rear, with increased length and width, reduced camber, and a large number of thin leaves of alloy steel carefully heat treated, with spring eyes having bronze bushings equipped with hardened and ground self-lubricating spring bolts. Scientific design and construction of truck springs for the loads, speeds and other conditions under which they are to be used has a very marked influence on the life of the vehicle

and especially of its tires. Spring design is now receiving the attention which in former years it lacked.

Axle spindles are universally equipped with adjustable tapered roller bearings in steel or malleable-iron wheel hubs.

Wheels either of cast steel or pressed steel are used to some extent, but wood wheels are still more generally in use in the United States. It is hardly to be doubted, however, that in time some standard construction of metal wheels will be adopted.

Tires on all types of commercial motor cars except light delivery wagons are of solid rubber compound, though the characteristics of the rubber vary as between tires for storage-battery electric trucks, where efficiency is of the utmost importance, and those used on gasolene trucks or tractor trucks, where efficiency is of less importance as compared with resistance to abrasion.

General Features of Design:

Location of engine under hood is practically universal—the new models of the type with driver over engine being carried over from earlier years. Weight carried on driving wheels ranges from 60% to 75% in the various sizes. Trucks of one ton and upward generally carry over 70% on rear wheels.

Left-hand steer and center control have been rapidly gaining in popularity, the 1915 models showing over 60% so equipped.

There is a wide variation in the maximum speed to which gasolene motor cars are limited by the governor setting, and the following speeds may be considered conservative practice for the respective sizes:

Size	Speed
Delivery wagons	20 m.p.h.
1-ton	19 "
2-ton	18 "
3-ton	15 "
4-ton	14 "
5-ton	12 "
7½-ton	10 "

COMPARISON OF GAS AND ELECTRIC TRUCKS.

The following summaries of operating costs of both electric and gasolene motor trucks are based on the best authenti-

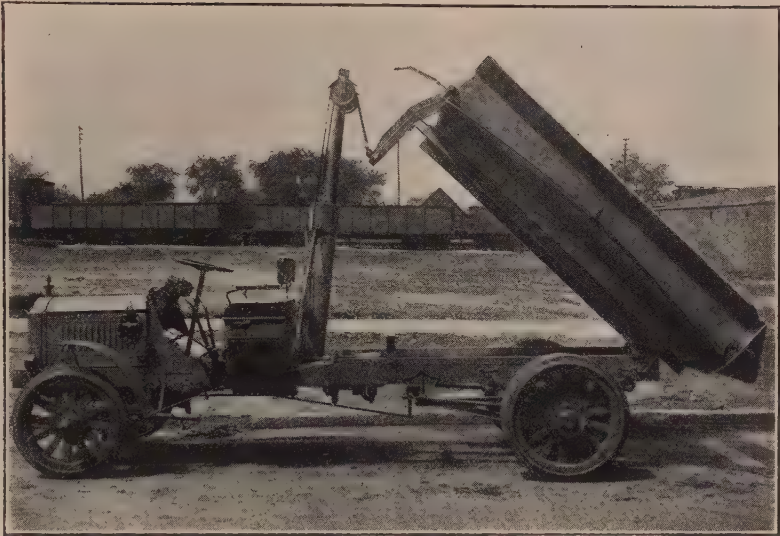

Fig. 4. "Packard" 3-Ton Worm-Driven Gasolene Truck, Power Dump.

cated figures covering the experience of both manufacturers and users, and show the average costs to be expected under usual but not exceptional conditions, with reasonably efficient management.

The items upon which these figures are based include the following:

- Interest on investment.
- Fire insurance.
- Depreciation.
- Battery repair and renewal (in case of electrics).
- Rubber tire renewal.
- Maintenance and repair of chassis and body.
- Electric current (in case of electrics).
- Gasolene (in case of gas trucks).
- Garage.
- Driver.
- Miscellaneous—Grease, oil, &c.

1-ton Electric—50 miles per day.

Total cost per year, 300 days	$2340.00
Total cost per day	7.80
Total cost per ton-mile	0.156

1-ton Gasolene—50 miles per day.	
Total cost per year, 300 days	$2770.00
Total cost per day	9.23
Total cost per ton-mile	0.185
1-ton Gasolene—75 miles per day.	
Total cost per year, 300 days	$3537.00
Total cost per day	11.79
Total cost per ton-mile	0.157
2-ton Electric—40 miles per day.	
Total cost per year, 300 days	$2580.00
Total cost per day	8.60
Total cost per ton-mile	0.108
2-ton Gasolene—40 miles per day.	
Total cost per year, 300 days	$2723.00
Total cost per day	9.08
Total cost per ton-mile	0.113
2-ton Gasolene—75 miles per day.	
Total cost per year, 300 days	$4000.00
Total cost per day	13.34
Total cost per ton-mile	0.089
3½-ton Electric—40 miles per day.	
Total cost per year, 300 days	$3011.00
Total cost per day	10.04
Total cost per ton-mile	0.072
3-ton Gasolene—40 miles per day.	
Total cost per year, 300 days	$3267.00
Total cost per day	10.89
Total cost per ton-mile	0.091
4-ton Gasolene—40 miles per day.	
Total cost per year, 300 days	$3697.00
Total cost per day	12.32
Total cost per ton-mile	0.077
3-ton Gasolene—75 miles per day.	
Total cost per year, 300 days	$4848.00
Total cost per day	16.16
Total cost per ton-mile	0.072
4-ton Gasolene—75 miles per day.	
Total cost per year, 300 days	$5742.00
Total cost per day	19.14
Total cost per ton-mile	0.064

Note: The above compares a 3½-ton electric with both a 3-ton and 4-ton gas truck, as there are but few of the latter type of machine rated at 3½ tons.

5-ton Electric—40 miles per day.

Total cost per year, 300 days	$3339.00
Total cost per day	11.13
Total cost per ton-mile	0.056

5-ton Gasolene—40 miles per day.

Total cost per year, 300 days	$3986.00
Total cost per day	13.29
Total cost per ton-mile	0.066

5-ton Gasolene—75 miles per day.

Total cost per year, 300 days	$5702.00
Total cost per day	19.01
Total cost per ton mile	0.051

In larger sizes of gasolene trucks, as for example 6, 6½ and 7½ tons, the ton-mile cost becomes further reduced. A 7½-ton truck can be operated 40 miles per day at a cost of less than 5 cts. per ton-mile, 60 miles at 4¼ cts., or 75 miles at 4 cts. Electric trucks are not generally built in these larger sizes.

From the foregoing figures it will be seen that the electric is the lowest in cost within its mileage limitations, while the gasolene truck is capable of covering greater distances, and for these increased distances its ton-mile cost is the lowest.

The figures show the comparative costs of the electric for its maximum mileage on one battery charge, and the gas truck for the same mileage. Also the costs of the gas truck at its maximum mileage for a normal working day.

The ton-mile cost of merchandise transportation on highways is still further reduced below the above figures by the use of trailers, to the extent of from 20 to 30 percent. The use of trailers (either 4-wheeled or 2-wheeled) is of such recent general application that sufficient data are not available to give general average figures, but it is not to be doubted that costs as low as 3 cts. per ton-mile can be reached under reasonably favorable conditions.

COMMERCIAL APPLICATIONS.

Both electric and gasolene trucks are successfully applied in all classes of service where merchandise and passengers are transported on streets or highways. To facilitate operation and obtain the best results in many classes of service, auxiliary devices of various kinds have been developed. These include the following:

Removable Bodies: These are especially intended for use where merchandise in packages is handled and where the time consumed in loading constitutes a considerable proportion of the working day. Upon arrival of the truck at the loading point a loaded body is substituted for the empty body by means of some power mechanism, such as an overhead crane installed at the loading platform or by means of some device such as a winch mounted on the truck and operated by its power plant.

Elevating and Dumping Bodies: In the coal trade and among contractors and others handling bulk material, bodies of these types are extensively used to facilitate discharge either from the back or side of truck. The operation is accomplished by means of an auxiliary mounted on the truck and driven by its power, and usually takes the form of either a mechanical, electrical or hydraulic mechanism.

Others who make use of auxiliary devices are: safe-hoisters, for hoisting safes to upper floors of buildings; electric companies, for hauling cables into subways; machinery handlers and riggers, for loading and unloading heavy machinery by power.

The extended use of such power-driven auxiliaries has recently brought about a new development of the gas electric vehicle.

GAS ELECTRICS.

This type of vehicle should not be confused with those brought out during a number of years past, several types being in satisfactory operation which are provided with electric transmission systems intended merely to take the place of mechanical transmissions for the propulsion of the vehicle.

The gas electric system here referred to consists of a gasolene engine governed to a constant speed, regardless of load imposed upon same. A compound-wound generator is direct connected to the engine and is wound for a constant voltage or for a falling voltage under increase of load, as may be required. The current from the generator is used to propel the vehicle through driving motors of the type used on storage-battery trucks and, in addition, furnishes current for the operation of auxiliaries driven by individual electric motors. These gas-

electric trucks may be built to carry the entire load upon their own chassis, or with shortened wheel base in the form of a tractor truck can haul 2- or 4-wheel trailers, upon which auxiliaries can be mounted. Extensive future development may be expected in connection with this type of vehicle. Its efficiency is no doubt lower than either the straight electric or straight gasolene, but its advantage lies in its having the simplicity of opera-

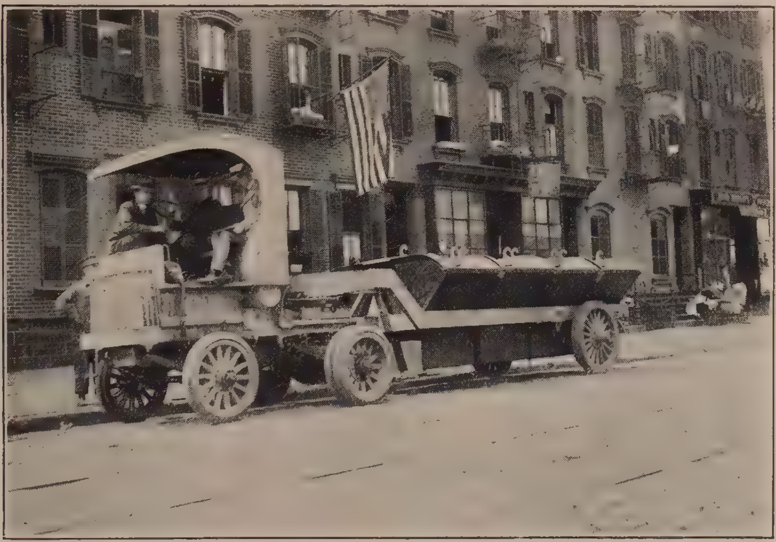

Fig. 5. "General Vehicle" 5-Ton Gas-Electric Tractor and 10-Ton Trailer for Refuse Collection.

tion of the electric, the unlimited mileage of the gasolene and the utmost convenience in the operation of auxiliaries. By reason of the high torque of its motors at low speeds it can haul excessively heavy loads.

TRAILERS.

The development of trailers for use in connection with motor trucks or motor tractors has been the result of the opportunities frequently occurring to haul additional merchandise loads in rear of the truck, thereby increasing the ton-mile capacity of the vehicle and reducing the ton-mile cost.

For a number of years past motor trucks built in Europe and subsidized for military purposes, particularly in France and

Germany, have been required to haul trailer loads of at least one half of the truck capacity. In the United States several of the leading truck manufacturers, recognizing the advantage of the use of trailers, have produced vehicles capable of performing this added service.

Trailers are of two general types: the four-wheeled trailer, which is merely hauled behind the truck; and the two-wheeled or semi-trailer, the forward end of which is supported by the truck. Extensive tests have shown that the power developed by the average motor truck is sufficient to haul

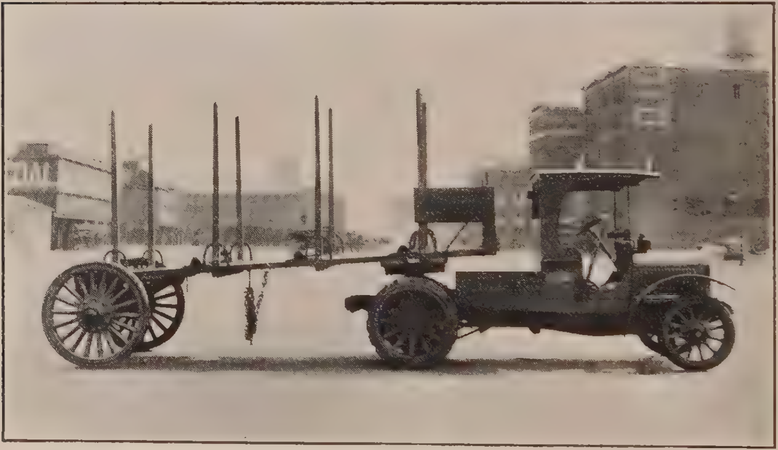

Fig. 6. "Saurer" 5-Ton Gasolene Tractor with 10-Ton Trailer.

a trailer load at least equal to the truck capacity, when operating under reasonably favorable conditions of roads and grades. In some cases it has even proved feasible to haul trains of trailers. To meet normal service conditions it is, however, customary on trucks designed to operate with trailers to provide a lower drive ratio, reducing the speed of the vehicle 15% to 20%, thereby making it possible to increase the total load capacity 100%. On chain-drive trucks this is easily accomplished by a change in sprockets. On shaft-drive trucks the gears or worm wheels must be changed.

The four-wheeled trailers of the most modern type are connected to the trucks hauling them by a linkage so arranged that the wheels of the trailer follow directly in track with the driv-

ing wheels of the truck. A notable instance of this design of trailer steers both front and rear wheels through the draw-bar, and they may be hauled in trains, all wheels tracking with the driving wheels of truck or tractor. This type of trailer is especially suitable for use on roads where traffic is light and where extreme overall length is not objectionable. In cities where there is any considerable congestion and the necessity may exist for backing into position for loading or unloading, the two-wheel type is preferable, though the four-wheel trailers may

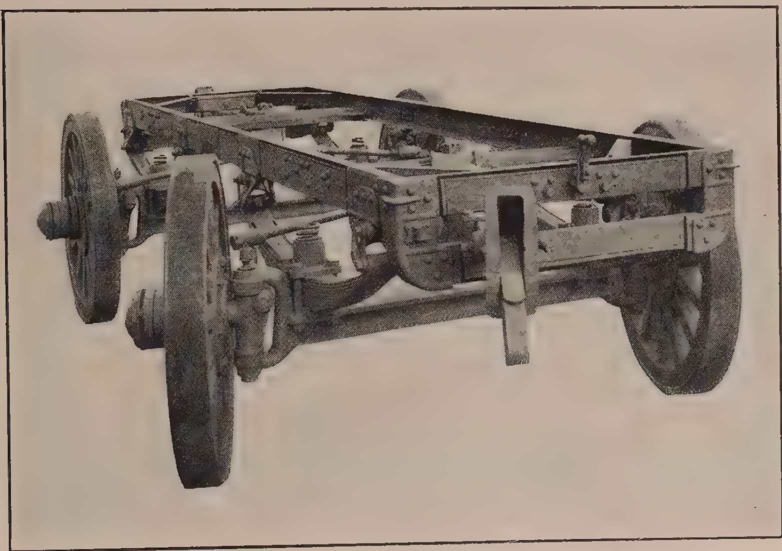

Fig. 7. "Troy" 5-Ton Double-End Trailer.

be backed by the use of a manually operated steering mechanism on the rear of the last trailer.

The two-wheeled or semi-trailer type in most instances is attached to its tractor truck through a fifth wheel, and the rear wheels of same do not track. One type of two-wheel trailer is in extensive service whose forward end is flexibly mounted on the tractor truck, and the rear wheels are mounted on a fifth wheel or turntable. By means of suitable linkage between the rear-axle unit and the tractor, the trailer wheels follow in track. A tractor truck equipped with a two-wheel trailer may be backed and placed in position with little inconvenience.

The use of trailers or semi-trailers, as outlined above, will doubtless be extended as time goes on, as the transportation cost per ton-mile is substantially reduced by their use, as has previously been pointed out.

Tractor trucks, whether of the electric, gasolene, or gas-electric type, must necessarily have their radius rods, driving mechanisms, speed ratio and number of speed changes adequately proportioned to the service which they will be called upon to

Fig. 8. De Dion Paris-Type Gasolene Bus; Internal Gear-Drive.

perform, but in view of past experience in Europe, as well as in this country, no obstacles of a serious nature, either in design or construction, present themselves.

SERVICE.

Passenger Transportation:

The use of standard motor-truck chasses as motor buses has become very general of recent years, and, as a rule, no special modification of the truck chassis has been made except to lengthen the frame in order to accommodate the maximum number of passengers. In London and Paris, however, as is well known, motor buses have been developed for the particular

purpose of carrying passengers without particular reference to the use of the same vehicle for merchandise transportation; though the latest type Paris buses were designed and subsidized for military purposes as well, and have been so used during the past year with great success. New York, which has the oldest and most successful motor-bus service in this country, adopted the Paris type of bus. The principal variations from American trucks found on these buses is that the

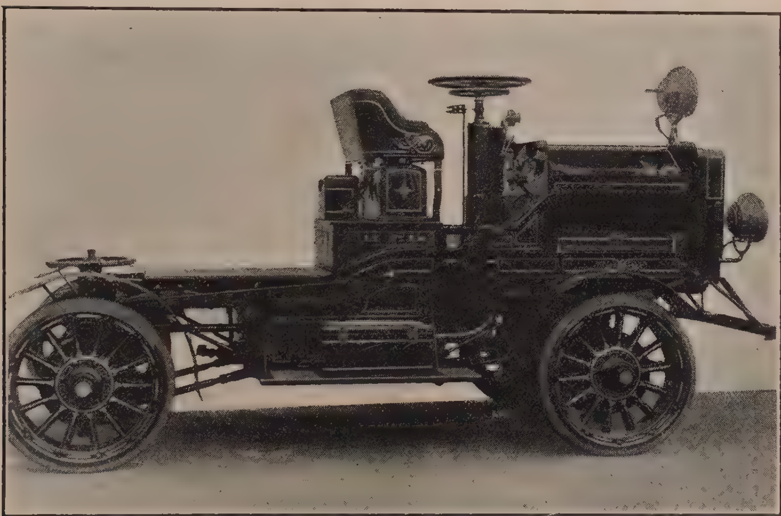

Fig. 9. ''Commercial Truck'' 4-Wheel-Driven Gas-Electric Tractor for Hook and Ladder Truck.

driver is placed over the engine in order to secure the maximum passenger capacity with a minimum overall length, on account of the congestion on some of the thoroughfares upon which these vehicles operate. Also, the radiator is of a coil-tube type with centrifugal fan, and the final drive is by pinions and internal cut gears on rear wheels. As previously mentioned, however, the internal gear drive is coming more and more into use, and these buses have doubtless had an influence in this direction.

Public Utility Service:

Fire department equipment probably takes the first place in the application of motor vehicles under this heading. No

standardization has as yet been reached, though the fire departments of American cities have been undergoing motorization gradually for more than ten years.

Electric, gasolene, and gas-electric applications have been made both in the form of self-contained machines and tractor trailers. Every branch of the fire department service has been motorized to a greater or less extent, some of the principal applications being as follows: Equipment of steam-driven pumping engines; hook and ladder trucks and water towers with tractors, thus utilizing equipment formerly drawn by horses; hose wagons, either for use with pumping engines or with high-

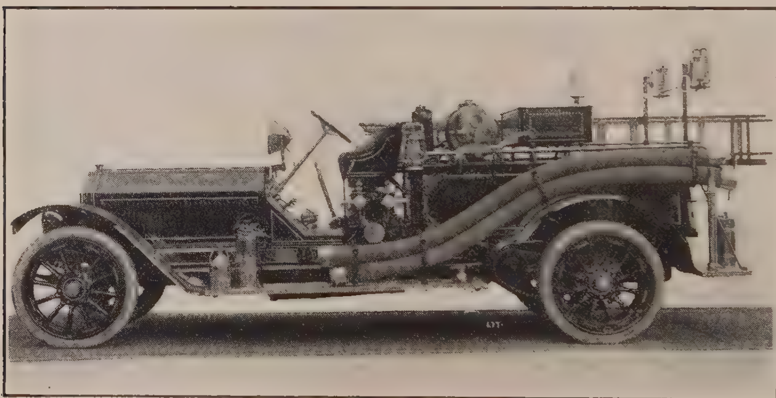

Fig. 10. "La France" Combination Pumping Engine.

pressure water mains, this equipment being usually of the self-contained gasolene truck type; city service trucks, with their equipment of chemical apparatus and hook and ladder equipment, also of the gasolene truck type; fuel wagons of the gasolene type; self-contained pumping engines, having pumps of the rotary or piston type driven by gasolene engines, which also furnish motive power for propelling the apparatus.

It is highly improbable that any material standardization in fire apparatus will be accomplished, as the requirements of different communities vary so widely.

Extensive experimentation has been carried on for a number of years in connection with the collection and disposal of refuse and the cleaning of streets by means of power-propelled

vehicles. These experiments have covered the fields of power-driven sweepers and flushers, motor trucks, and tractors of both the storage-battery electric and the gasolene type. Varying conditions in each community seem likely to prevent any standard apparatus being produced suitable for universal application, but in many of the larger cities the gas-electric tractor and trailer system, with suitable auxiliaries mounted on trailers of various types, will probably be the solution.

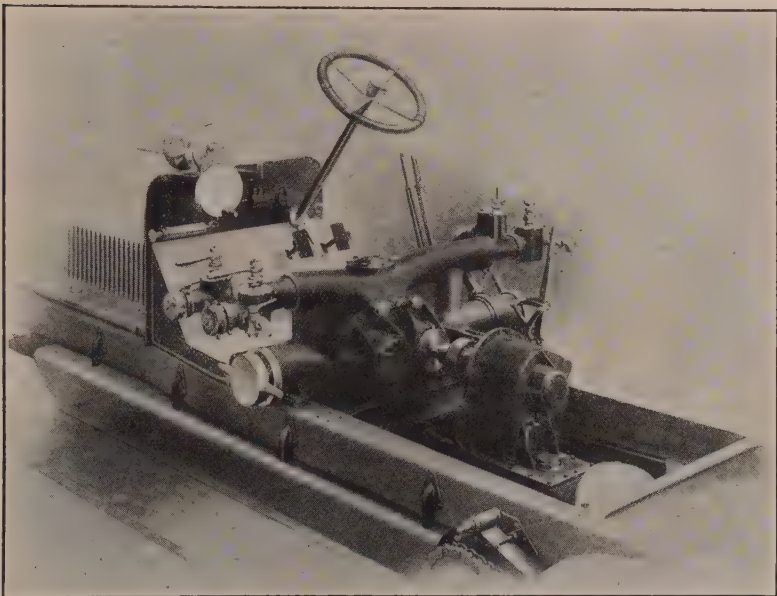

Fig. 11. "La France" Pump Showing Mounting and Driving Connections.

Other public or semi-public functions performed by commercial motor cars include: Hospital ambulance service; tower wagons for street-railway line repair; emergency and wrecking wagons; and trucks for the transportation of materials in numerous municipal departments. In these lines of work both gasolene and electric vehicles are used as the requirements of the service indicate to be desirable.

STANDARDIZATION AND SPECIALIZATION.

The observation of the author during the past decade leads him to conclude that the future development of the motor-

truck industry will be along the lines of standardizing the general design of vehicles of various types and carrying capacities, so that component parts made by those specializing in their manufacture can be made to a large extent interchangeable and of uniform general dimensions. Thus manufacturers of parts, such as engine, axles, transmissions, etc., will be enabled to manufacture in quantity, thereby reducing production cost without any sacrifice of quality, and the truck manufacturer

Fig. 12. "General Vehicle" Storage-Battery Electric Front-Wheel-Driven Dump Cart.

will be able to select the units best adapted to harmonize with his general design, without requiring special parts to be manufactured at increased cost and with delays in deliveries. The Society of Automobile Engineers has been devoting practically its entire energies to standardization work for the past five years and has accomplished much in this direction.

BIBLIOGRAPHY.

In a branch of engineering which has attained such proportions in so short a time as that covered in this paper, and

which is making such rapid progress, it seems impractical to attempt a bibliography. In general the files and current issues of the trade press, especially "The Commercial Vehicle", "Power Wagon" and "The Commercial Car Journal"; the Hand-Books of the Society of Automobile Engineers, containing Data Sheets frequently revised and bound in loose-leaf form, and the monthly Bulletins and semi-annual Transactions of that Society are the sources from which data and information on the subjects touched upon in this paper can be obtained.

Note:—All discussion pertaining to motor vehicles will be found at the end of Paper No. 132.

Paper No. 132

MOTOR TRACTORS.*

By

FRANK S. DAVIS
Mem. Soc. Auto Engrs.
Chicago, Ill., U. S. A.

"TRACTOR".

The term "tractor" is in reality a short form, the outgrowth of the term "traction engine" and more particularly pertains to the class of machines deriving their power from an internal combustion engine. While the word is of comparatively recent coinage, the manufacturers of this class of machinery have universally adopted the term and its definition is generally known and accepted in this branch of engineering and throughout the farming world.

EARLY DEVELOPMENT.

Within the past ten years and after the internal combustion engine had proved an unqualified success, the motor tractor was developed. The inception of this type of traction engine was no doubt brought about through the desire to displace the cumbersome, heavy and inefficient steam traction engine, having further in view the expense entailed in transporting the requisite fuel and water needed with the latter type of engine. This difficulty of transportation of fuel was almost insurmountable on the great ranch lands of the Far West, which, during this period, were being brought under cultivation by grain farmers. The motor tractor was so much lighter, and for that reason so much more efficient in tractive effort than the steam traction engine, that at once it began to displace great numbers of horses which were then employed in breaking up, for grain growing, the immense tracts of virgin land to be found in the West and Northwest of this country, as well as in Canada.

* The writer is much indebted to Mr. H. D. MacDonald for considerable assistance in the preparation of this paper.

To the Western farmer belongs the honor, in accepting these pioneer efforts of the tractor designer and manufacturer, and through his acceptance of these somewhat crude machines the foundation was laid for the immense tractor business of today. To him also must be given credit for his ingenuity in overcoming trouble and for persistent effort in operating these earlier machines under adverse conditions.

The tractors first developed were of comparatively small horsepower, but on account of the insistent demand for increased drawbar power, the manufacturers eventually put forth machines of double and even treble the power of the earlier machines. These more powerful machines were successful in plowing or breaking up large tracts of range land.

On account of this success, the farmers of the Middle West were gradually tempted to follow in the footsteps of their more progressive Western brothers of the farming industry. This venture, however, was not entirely successful in plowing work, due to the smaller-sized farms necessitating smaller tractors which would be more nearly proportionate to their needs. They proved, however, eminently successful in threshing work, on account of the large-sized grain separators extensively used in those sections of the country. Another feature of development brought about in the invasion of the Central West by the large tractor was the good-roads movement started several years ago and which is now fast attracting universal attention.

The Eastern farmers, due largely to their conservative ideas as well as to the restricted size of their farms, did not take kindly to the motor tractor of that period, and although there were a few operated for farming work, there was practically no demand for them. It is not to be inferred that this tractor was not, at least to some extent, in use in the East and Middle West, but its usefulness was largely limited to contractors' work, for hauling purposes or for the work customarily done by the portable engine.

INFLUENCE OF FUEL ON TRACTOR DEVELOPMENT.

The rapid development of the motor tractor, largely due to the success of the internal combustion engine, has, nevertheless, through the research work carried on, and the overcoming of

conditions which had to be met in its development, greatly benefited the branch of engineering concerned with the design of oil engines for stationary purposes.

The present-day successful tractor differs from the earlier motor tractor first, and most important, as to the kind of fuel consumed. Gasoline was the fuel used on all of the earlier types, but on account of the enormous demand for gasoline by the ever increasing number of automobiles, the price has increased to a practically prohibitive figure for industrial purposes, and therefore a heavy oil-burning type of internal-combustion engine was developed, and at the present time many makes of tractors are so equipped. Most of the engines now used are of a very simple type and are easily operated by the labor ordinarily found on the farm. Kerosene and distillate stationary engines have been built for several years, but generally their design has proved altogether too heavy for tractor use and far too complicated to operate when placed in the hands of the above grade of labor.

There are, however, some makes of tractors, of the multi-cylinder type, which adhere to gasoline or to a mixture of gasoline and kerosene, on account of the extreme difficulty in successfully carrying the atomized mixture to the various cylinders through long and tortuous manifolds. The fluctuating load of the tractor makes this a particularly difficult problem to solve, and even though denied by manufacturers of the multi-cylinder type, which are advertised to run on distillate and kerosene, there is no doubt but that the low-speed heavy-duty oil engines, of single or double cylinder, are most successfully operated by the class of labor usually employed.

Some sixty manufacturers of tractors are now endeavoring to market machines. Among these we find gasoline motors and those that burn kerosene and distillate, single, double and multi-cylinder type. Those who still build the gasoline type maintain that the fuel consumption is so much greater on kerosene that they can operate cheaper on gasoline, and they are able by good salesmanship to convince some that this claim is true. Still other makers advertise their machines as kerosene-burning outfits, but at the same time advise the use of gasoline, for reasons aforesaid. They merely use the kerosene claim as a

ruse and then advocate the use of gasoline, so as not to be called upon to make good. Still other, and the most successful builders, advocate kerosene and distillate only and are always prepared to prove the economy of their machines by using these heavier oils in practical demonstrations. In fact, there are several—and they rank in the foremost—who absolutely use nothing but kerosene or distillates of 36 to 39 degrees Baumé in the process of test at their own factories, and these machines, in the hands of farm operators, run continuously on these low-grade fuels.

The following data, derived from representative types, will give a conservative idea as to the comparative consumption of the different fuels at full load:

Kerosene, average	0.1125 gallon per hp.-hour
Gasoline, average	0.1000 gallon per hp.-hour

This shows an increase of 12½% when burning kerosene. Taking the average cost of gasoline at 15 cents per gallon and low grade kerosene at 7 cents, we have in comparison with every gallon of gasoline at 15 cents 1⅛ gallons of kerosene at 7 cents ($0.07875). When purchasing fuel in small quantities these figures are seldom bettered, but when buying in large quantities the kerosene figure may be cut down 1/3. In fact, many users of distillate are purchasing this fuel as low as 3 to 4 cents per gallon. The distillate mentioned is a lower grade of fuel than kerosene, with a gravity varying from 36 to 39 degrees Baumé, and can be obtained readily throughout the Middle West and East. It is a semi-refined oil, usually quite clear, nearly colorless and with a slight odor of crude petroleum. Gasoline purchased in large quantities will seldom find a reduction in price of more than 15% of the figure given above.

Figure 1, a fuel consumption diagram, shows economy curves for these fuels. Another feature prominently brought out by this diagram, and one of which most manufacturers are cognizant, but are not prone to dwell upon, is the rapid drop in efficiency of the internal combustion engine when used at light loads. In corroboration of the above, this feature regarding fuel consumption and economy of operation will be referred to later under "Trend".

TYPES OF MOTORS USED ON PRESENT-DAY TRACTORS.

Of a list of fifty-nine manufacturers of tractors, in this country, thirty-five build, or rather list, a 4-cycle vertical kerosene-burning type of engine. As a matter of fact, there are twenty-seven of these manufacturers using automobile motors and the other eight use an engine specially designed for tractor purposes. While thirty of the latter adopt and claim the

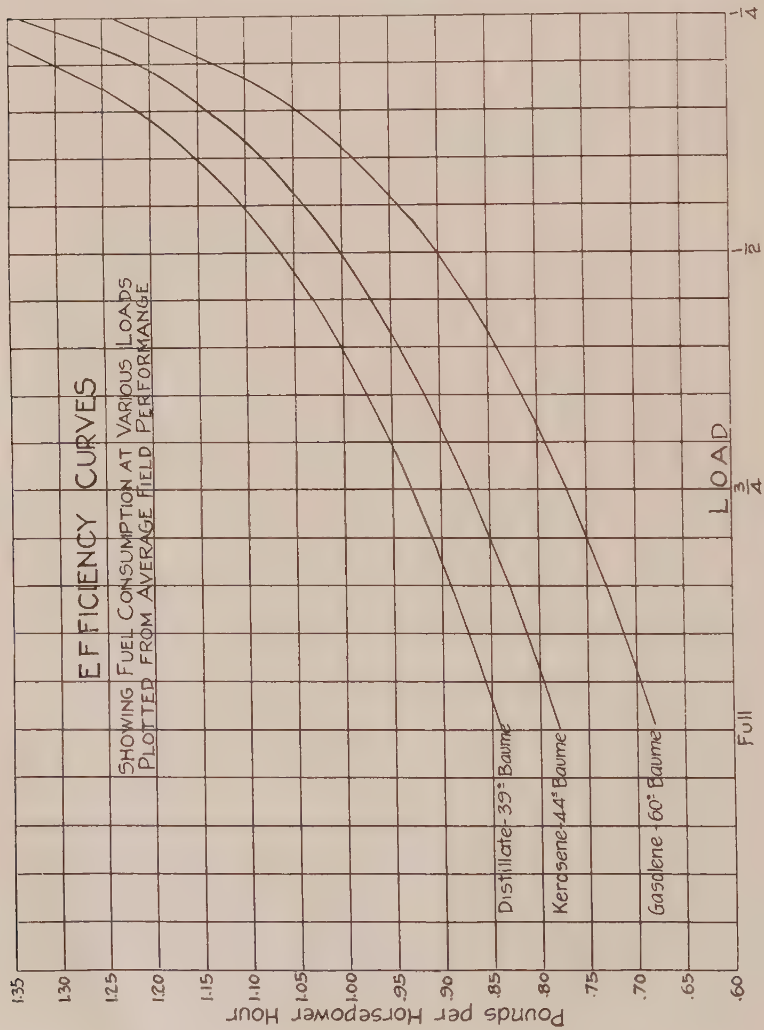

Fig. 1.

use of kerosene, it is well known in the trade, that there are not more than seven makes that operate on kerosene with any degree of success, and most of these only when in the hands of skilled operators and where the performance is limited to practically a steady load. It has been demonstrated, however, time and again, that nearly all of the four-cylinder makes of tractors can be made to operate in the demonstration field on a mixture of ½ gasoline and ½ kerosene.

It is erroneous to assume, because the manufacturers of four-cylinder tractors are in the majority, that they are the most successful, or that there are more of those tractors in operation, or likely to be so in the near future, than any other type. As a matter of fact, they constitute a very small percentage of the total number of tractors manufactured, sold, or in use today. Not more than five makes of four-cylinder tractors have in any way fully established their claims of being in the "successful tractor class", while the single and two-cylinder heavy-duty engine tractors have long proved their claims, both as to durability and successful operation on heavy oils, with even the lowest grade of operators.

The successful operation of the last-mentioned tractors on kerosene and heavy distillates is directly due to a large amount of costly experimental and research work carried out by manufacturers, who have aimed to obtain the desired end by simplicity of construction of the engine and its mixer. The latter is practically automatic in its action, leaving no fine-haired adjustments to be made by the operator.

Another point given particular attention is the heat regulation of the cooling system, which is vitally necessary to the successful burning of kerosene. One prominent manufacturer maintains a constant cylinder-water temperature, regardless of the load, and others, also prominent, have attained somewhat the same results by the employment of a very light oil as a cooling medium for the cylinders.

Too much stress cannot be laid upon the fact that the real makers of the tractor business, by their years of experimentation and testing (one concern carries on plowing work on its own lands in the South) are the ones to govern, and after this extensive work and the building up of a business to its pres-

ent proportions, such hastily thrown together machines as those equipped with the automobile type of engine should absolutely be eliminated from further consideration. Most of these are designed by inexperienced engineers, who with some particular idea as to drive, or truck, or wheels, believe they have the real one, accepting as a foregone conclusion, the standard gasoline engine. These are all new and, as proven in the past, an unstable product.

The results of the tractor industry that have proved a success are not the product of some wild dream of an inventor, but show intelligent and careful design, carried out by engineers who have devoted their entire energy and undivided time to this work during the past decade.

We will therefore eliminate from consideration all but those of reliable make. Summing up, after careful study, there are to be found—

9 of the 2- and 4-cylinder horizontal opposed type.
6 of the 2- and 4-cylinder horizontal type.
4 of the single-cylinder horizontal type.
6 of the 4-cylinder vertical type.

We will now take up the four principal or leading types of engines used.

The 2- and 4-cylinder horizontal opposed engines, aside from the advantage gained by their being naturally balanced, have proved less difficult of cylinder lubrication than the vertical type without splash system. The burning of kerosene or distillate absolutely precludes the use of the latter system, because these heavier oils tend to destroy lubrication, and further, as the mixture used is an atomized one, there is considerable condensation on the walls of the cylinder, a certain amount of which cannot be prevented from passing by the piston and rings, mixing with the lubricating oils and rendering it unfit for further lubricating purposes. Similar advantages in lubrication must be attributed to the 1-, 2- and 4-cylinder horizontal.

The types of engines first mentioned are peculiarly adapted to tractor use, in so far as they can be readily cross mounted on the tractor frame, which enables a direct drive, by means of

spur or chain gearing, to the countershaft or rear axle. This is a great aid to simple construction and efficient drive.

The six- and four-cylinder vertical types have, of course, the advantage of smooth running, but on account of their length, it is necessary to mount them fore and aft of the frame. A cross mounting is obstructive to the view of the operator, unless cab and platform are extremely elevated. This, aside from lending the appearance of a massive, cumbersome machine of awkward construction, is not looked upon with favor by the farmers. The disadvantage of fore-and-aft mounting is the bevel gear construction of drive, causing loss of power and making complicated construction for belt work. In this, it is necessary to drive through bevel gears—a bad feature for continuous power drive—or belt drive sideways from machine, which presents difficulties in the aligning and tightening of belt.

Inasmuch as the tractor must perform tractive and belt work and as belting from pulley on crank shaft is better than through other mechanism, it must be conceded that the cross mounting of the crank shaft of any type of engine is, with regard to the aligning and tightening of belts, absolutely the best.

TRACTOR CONSTRUCTION.

Frame.

It has been the aim of the majority of tractor engineers to construct a light, rigid frame of great strength, of either a built-up and trussed type, or standard "I"-beams and channels, riveted and bolted together by angles and gusset plates, each of which has proved its durability.

Drive Mechanism.

It has been found by most of the successful manufacturers that a complete spur-gear drive to the rear wheels, or to the counter shaft and thence by chain to the rear wheels, makes toward mechanical simplicity and higher efficiency more than any other form or type of drive. The drive to the rear wheels, whether by chain or internal or external spur gearing, has, up to the present, presented great difficulties in properly guarding these parts from excessive wear, due to the dust, dirt and sand carried to them by the rear wheels, and also, in some cases, to the close proximity of some of these parts to the ground.

Open gears without guards are liable to be broken by stones and undue wear from other causes mentioned. Some manufacturers have entirely neglected this feature, while others have made poor attempts at chain and gear guarding. The guards generally catch a large quantity of dust, dirt, mud and sand, and decidedly aid the cutting-out or wearing process instead of remedying it. A few manufacturers have put forth guards which serve their purpose fairly well under most working conditions.

The difficulties with gear guarding are, that if a cheap partial guard is provided which keeps stones, clods of mud and ice from entering the gearing, it does not protect it from dust, and to be most efficiently guarded from these troubles complete guards should be installed which would be absolutely dust tight, and this means the equivalent of oil- or water-tight. It has been found that a guard of the type just mentioned has not, and seemingly cannot, be successfully applied to the present type of bull gear-driven wheel universally used on the larger-sized tractors. As stated before, the gearing guards should be absolutely water- and oil-tight; otherwise no attempt at all should be made to have a casing proof against the action of dust, mud or sand, but rather provide a short upper guard to exclude the danger of stones, clods of earth or ice from falling on the gears and causing breakage.

Some later models of large tractors have eliminated the bull-gear or guarding difficulty by resorting to an entirely different design, in which these gears are entirely enclosed in a gear case running in oil and drive the rear-wheel hub by jaw clutched sleeves. No running bearings, gear contacts or working joints are thereby presented to the dirt.

Wheels.

The two common types of wheel are those in which round or flat radial spokes are used; and in nearly all cases extension rims are provided and are furnished in various widths, depending largely on the weight and size of tractor.

Nearly all rear wheels on the later model tractors are mounted on live rear axles. The lesson the steam-traction-engine manufacturers learned has been taken advantage of by the present-day tractor designers, as the mounting of wheels

on stub or stationary-type axles caused the wheel bearings to be short lived, because it was found impossible to make a bearing of sufficient length to be proportionate to the diameter of the wheel and at the same time maintain a reasonable overall width of tractor.

Front Axle and Steering.

There are practically only two types of front axles used: one the pivoted stub axle, or better known as the automobile type and controlled by similar means; the other is the well-known solid "dead axle" pivoted in the center to the front bolster of tractor frame, and is the same as generally used on the steam traction engine where the control is by chains passed over a worm-operated roller.

Spring Mounting.

All of the large, heavy types of tractors, geared to run at a single or plowing speed, are of rigid construction, no attempt having been made for absorbing shocks by the use of springs between axles and frame, while in some of the lighter two-speed machines such springs have been a leading feature and have proved of great value when used on hard roads or rough ground.

Steering Devices.

There are several makes of automatic steering devices for guiding the tractor when on plowing work. The basis of all of these devices is a furrow control of a guide wheel or wheels. Nearly all of them perform well even under the worst conditions. Some are of very simple design and accomplish the purpose by the use of very few parts, while others are rather trappy and complicated.

Materials.

Special steels have not been commonly used in tractor work except by a very few of the largest manufacturers, and they could afford their use only through ability to purchase from the steel manufacturer in large quantities. This also applies to special rolled sections, such as tire stock, etc.

Special casting mixtures in gray iron and steel have generally been resorted to for both strength and lightness of construction. Heat treatment of steels, pistons, etc., and special analysis of bearing metals,—all have been given special atten-

tion and development by the older and more advanced manufacturers.

Starting Mechanism.

There are two general classes of starting mechanisms applied to the tractor motor or engine, viz., hand and power.

Hand Starting.

This heading primarily pertains to the several hand-operated reduction-gearing devices and must cover also tractor engines where no special devices are used and where the operator starts the engine by means of a simple hand crank on crank-shaft or turns the engine over by pulling directly on the flywheel.

Power Starting.

In this class of starting will be found three different forms:

1. Air starting in its common form, which comprises a storage tank in which compressed air has been accumulated by the power of the tractor engine during its preceding run.

2. That which includes an air storage tank in a system entirely separate from the large engine and in which is employed a small gasoline engine-compressor, making this system complete in itself; and if the air in the tank is lost through ineffectual starting, the small engine-compressor is immediately brought into action and replenishes the air storage tanks. In this system is eliminated the labor often required for compressing air by hand to refill storage tanks, or turning the engine over by hand, which must be resorted to by the first described air system and which thereby defeats entirely the object of power starting.

3. In which is employed power direct from a starting engine delivering its power direct to the flywheel of the tractor engine, generally by means of friction gearing. Of all power starting devices this form has proved to be the most efficient and reliable.

ROAD WORK.

Road work generally applies to two entirely different classes of work. One pertains to road hauling work, such as hauling of grain, stone or other materials over roads where shipping facilities are poor; the other pertains to road-making

work or highway construction. Both of these vastly different kinds of road work are spoken of, referred to and discussed under the heading of road work. They should be properly subdivided under classes as "road hauling work", and "road-making work" or "highway construction".

We will now consider the adaptability of the present-day tractor to these classes of work, first considering "road hauling work". The tractor in the hands of the farmer for hauling purposes on the road has proved successful, and on the large

Fig. 2. A 12-25 H. P. Tractor Hauling Six Wagon Loads of Brick, 4500 lbs. Each (Total 27,000 lb.) in Florida.

Western farms where they are compelled to use tractors, this method of conveying grain to the elevator for shipment by rail is being employed. In some instances ranch owners raising grain as far as 50 miles from a railroad or town must so employ the tractor, and loads in wagon train of 60,000 to 80,000 pounds, amounting to from 600 to 800 bushels of wheat, are not uncommon sights, with the large tractor plodding away at a horse-walk speed. Many specific cases of more-than-satisfied owners can be cited, it being well known to all of them that in the absence of such machines the difficulties and expenses of trans-

portation would be practically insurmountable. Teams, of course, could be so employed, but the great number of them required would entail a much greater expense, as would also the use of auto trucks. The tractor is best adapted because it first prepares the land, harvests the grain, furnishes power for its threshing and then, in natural sequence, hauls it to the desired point for shipment. In the actual performance of this hauling work and in connection herewith the writer presents photographs (Figures 2, 3 and 4) showing a few representative types of road hauling machines. This part of the subject, if taken up in detail, would form a complete subject in itself, but due to limited space, this must serve to impress the reader with

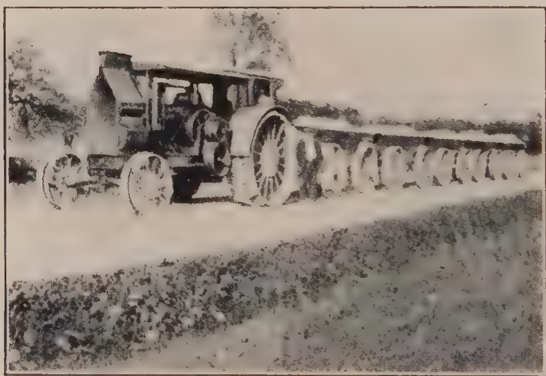

Fig. 3. A Large Tractor Hauling Crushed Rock for Road Improvement.

the importance of road hauling work and the great room for advancing in this field. The adaptability of the present day tractor varies with different makes; however, this will be referred to in a subsequent part of the paper.

Road-making work or highway construction, also commonly referred to as road work, includes the cutting of new dirt or clay roads and the grading, re-grading or leveling of old roads. Township activities in the Middle West, along these lines, have been pushed to the extreme and the value of the tractor in making roads, as well as in their upkeep or maintenance, over the use of horses, has been featured by many on a basis of the comparative actual cost per mile. In fact, figures here are unnecessary, because only through the use of the

Fig. 4. Tractor Hauling Complete Farm Equipment Near Weyburn, Sask.

tractor was this extensive work accomplished. Figures 5, 6, 7 exhibit clearly these classes of road work in operation. Appropriately here, may also be mentioned macadam road and boule-

Fig. 5. First Operation in the Construction of a New Road.

vard construction; but in this connection we find the uses of the present-day tractor confined to the hauling of materials and in some cases supplying belt power to concrete, cement or macadam mixers, instead of actually displacing the steam

roller. There are a few machines on the market in which such displacement is attempted, but the efforts of the manufacturers have thus far proved only partially successful.

Fig. 6. A Six-Foot Grader in Operation.

AGRICULTURAL USES.

Under this heading we find the classes of work for which the tractor was primarily designed and developed, and we will consider these uses under four sub-divisions, namely:

Fig. 7. Road Leveller in Operation.

(1) Preparing, clearing or grubbing, including stump-pulling, of land otherwise unadaptable for grain farming.

(2) Breaking, plowing, deep tilling, harrowing, disking, seeding and rolling or packing. (See Figures 8 and 9.)

(3) Harvesting. (See Figure 10.)

(4) Threshing (see Fig. 11), ensilage cutting and silo filling, feed grinding, corn husking, corn shredding, corn shelling, sawing, and other belt work.

(1) On account of the previous high cost of clearing land for farming, the motor tractor has proven very efficient, successfully cutting and plowing-under ordinary brush, partially

Fig. 8. Plowing with 10-14 in. Bottoms in Nebraska.

decayed stumps and roots, while the larger and more solid stumps are quickly pulled without the aid of elaborate rigging. This work is now done for one sixth to one tenth the cost it was formerly done for, where teams were employed. The plow makers have coöperated well with the tractor manufacturers in producing heavy, specially-designed grubbing plows. A single, 24-in. bottom plow is frequently used, and this generally requires a tractor of 30-hp. capacity at the draw-bar.

Due to the marked improvement in heavy plow construction, and since the advent of the oil tractor, the cost of clear-

ing land has been so small when compared to its greatly enhanced value that many have taken advantage of this and have reaped a rich reward for their enterprise.

(2) Undoubtedly, breaking or plowing is the hardest or most severe work that has to be done on the farm, whether performed by horses or tractor, for as a rule the time for doing this work is generally limited, especially so in spring plowing if the season is late and has been preceded by wet weather. In

Fig. 9. Tractor Disking.

this case the farmer who owns a good tractor and plowing outfit can wait for the most favorable time before starting to plow and still finish ahead of his less progressive brother who uses horses. Again, if found necessary to push the work faster than at first contemplated, possibly on account of a threatened change in weather conditions, another crew can be employed and the full twenty-four hours taken advantage of. In the extreme Northwest and in Canada, this is often done, time for

performing the work being very limited on account of the shortness of the seasons.

In the main part of the country, when conditions are right, disking, seeding and rolling or packing is done at the same time where tractors are employed, thus reducing the costs of these operations to a minimum. Summer and early fall plowing are particularly severe on horses because of the conditions due to heat and flies, and as the farmer is careful not to overwork his teams, frequent stops are necessary for resting. Ground conditions, often unfavorable, directly increase the cost of doing this work over what it would have cost earlier in the

Fig. 10. Harvesting with Tractor.

year; but the tractor goes at the same speed and does the same work and only asks for one condition, viz., a fair footing; with this it will do its duty day after day, and for a day of twenty-four hours if need be, and with far less fatigue to the farmer.

The tractor has made possible deep tilling, and the rapid progress of this method of preparing the land has reached such magnitude and has commanded so much attention in the farming world that this is manifestly a branch of study in itself. Further, it has only been brought about by having available ample power for continuous service and surplus energy for momentary overloads.

Fig. 11. Typical Threshing Scene, Lexington, Nebraska.

(3) In harvesting, the tractor has not as yet been so universally employed, and instances of its use have been few and far between, due to the fact that the tractor of the past has been primarily built for plowing work. A machine of 8- to 12-plow capacity, as used on the large Western farms, where the employment of a large tractor would be warranted in harvesting, would handle 5 or more binders. But in the case of trouble with draft gear, or other troubles contingent on the combined operation of the binders, this arrangement would not allow the stoppage of one machine only for a momentary adjustment or correction, but would necessitate a complete cessation of work for all. But this difficulty has now been overcome by the production of the small tractor which is capable of handling one or two binders. Small tractors of this capacity more nearly fill the farmer's requirements and come nearer to the replacement of horses than do the large tractors of greater horsepower.

(4) In threshing work the present motor tractor competes with its older rival, steam, which up to the days of introducing the oil engine, more than held its own. But as the comparatively few heavy-duty types of tractors have proved beyond a doubt their reliability, economy, simplicity in handling and ease of operation, and have eliminated fire risks, etc., as well, the employment of this motive power is rapidly superseding steam, even among the oldest and most conservative of threshermen.

PRESENT STATUS.

The present day in the tractor world is very unsettled, there being no real demand in the tractor business, because the farmer of the past did not know what he wanted. In the automobile business, which is just a decade older, there is a pronounced demand by the general public for small cars. This demand has been created by the past decade of experience with the automobile. So it is with the present farmer, whom the many manufacturers of widely different types advise that their machines are the type he needs.

For those not familiar with these matters, it may be well to express the opinion that the present-day successful tractor

is a small machine capable of handling two or three plows. It need not necessarily be of the four-cylinder, high-speed type, because, while comparing the history of the tractor to that of the automobile a few years back, it must be remembered that the tractor for farm purposes must perform two functions, whereas the automobile primarily performs one. Lightness of construction, quiet running and least vibration were gained by the multiple-cylinder construction, which ultimately solved the automobile problem. But this was done by sacrificing economy. This same tendency has been adhered to by some manufacturers in types of the present four-cylinder machine, and some farmers have accepted this type of machine for the same reasons as given for the automobile. But the tractor must do belt work, which requires maximum power constantly for many hours. In comparison with this the average automobile does but a small amount of work, with such exceptions as during races and endurance runs, after which the engines are invariably overhauled, or if not, the remaining life of the machine is short when compared with the farm tractor. The multiple-cylinder automobile engine is successful for the reason that maximum power is used on an average of less than 15% of the running time.

The tractor will be used in plowing continuously, day in and day out, on a maximum load, and in threshing, a like amount of time under heavy loads. During these periods it is required to develop an amount of power proportionate to that which the automobile develops in races, and which soon relegates these engines, or at least many parts of them, to the scrap heap in much less time than the farmer will tolerate. This statement refers to the tractor as accepted by the farmer in general.

The tractor as above described is one of the next decade and the one which at present the sixty-odd tractor builders (so-called) are unconsciously striving to obtain. While this small machine of two-plow capacity will (in this country) be universally manufactured and used, a certain number of brainy and to-be-wealthy farmers (and the class will extend itself greatly) will demand a more specialized tractor. This demand will always be met by a few conservative manufacturers pro-

ducing two separate and special machines, one for traction power and one for belt work. This condition must necessarily follow, because a combination machine which serves the purpose of the small farmer does not give room for mechanical genius to put forth the best machine for either purpose.

TREND OF ULTIMATE DEVELOPMENT.

The reason for the great number of different designs and styles in tractors of the present day is that most manufacturers are striving to make a general purpose machine. Each manufacturer produces a machine which is successful in the particular work for which its design is adapted, but which fails in other classes of work. For example:

1. A machine for hauling on roads, in which is found spring mounting, power steering and a quiet-running engine of multiple-cylinder construction, in fact of construction similar to the present well-designed auto truck, with functional exceptions, will be so constructed as to utilize its carrying capacity in tractive effort while the present truck carries its load on its own wheels. This semi-truck which is fundamentally a hauling machine may possibly have more than one motor or prime mover, keeping in mind economy of operation by this arrangement. Reference to Figure 1—"Efficiency Curves"—will illustrate the reason for this second engine. Under light loads one motor only may be used at a larger proportion of its maximum power, and consequently more economically. A single engine of this combined power would in such case be operated at low comparative power and therefore inefficiently.

2. A machine for plowing in which the plows are specially designed and mounted as a unit in the same frame as the engine, all to be of lightest possible construction consistent with the work.

3. A machine for road making in which will be found the grading blades mounted in the tractor frame.

4. A power roller for street and boulevard construction.

5. A self-propelling machine for threshing which will eventually comprise a thresher with the power mounted directly on it.

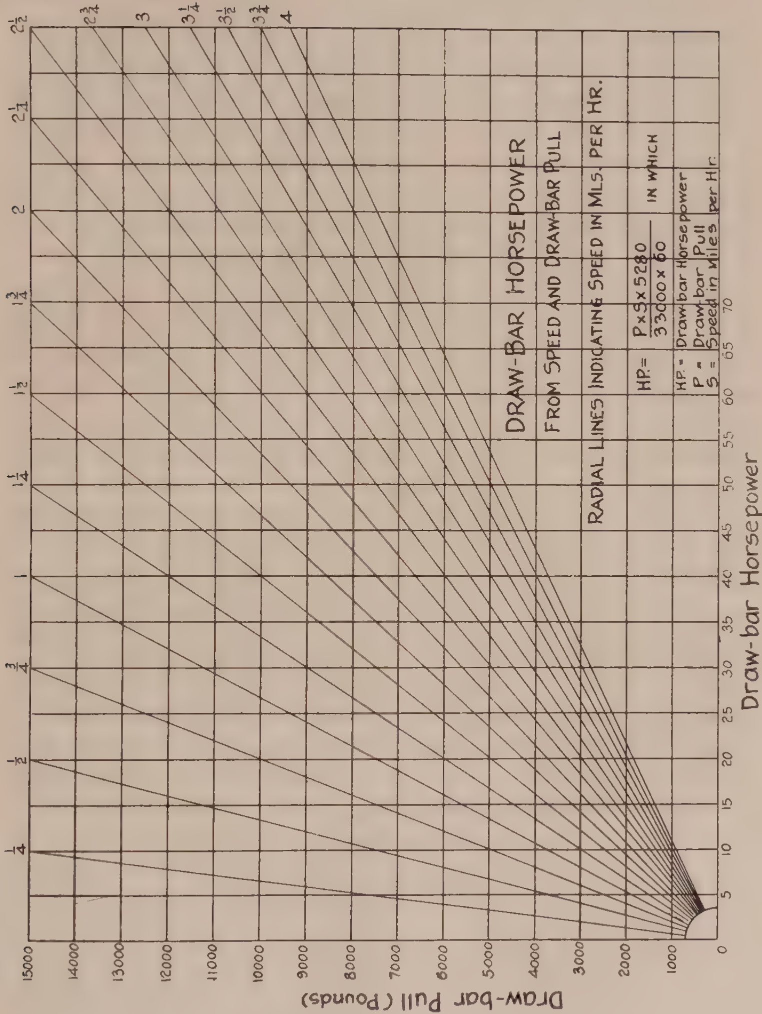
DRAW-BAR HORSEPOWER
FROM SPEED AND DRAW-BAR PULL
RADIAL LINES INDICATING SPEED IN MLS. PER HR.
HP.= $\frac{P \times S \times 5280}{33000 \times 60}$ IN WHICH
HP. = Draw-bar Horsepower
P = Draw-bar Pull
S = Speed in Miles per Hr.
Draw-bar Horsepower
Draw-bar Pull (Pounds)

Fig. 12.

(6) A machine for belt work which in reality will be a self-propelling portable engine.

Manufacturers of each of the foregoing should embody in their machines principles especially adapted to their particular work and not try to make a "jack of all trades" machine similar to a combination tool, which is recognized as inefficient in its entirety. They should aim to ultimately standardize the design of each of these types and discard most of the past and present-day efforts.

The motor tractor, as displacing the steam traction engine, was conceded by all to be a farm engine primarily for plowing and threshing, and in due sequence some of these machines were sold and used on country road construction, rather effectively, but inefficiently. Their use on road hauling work was also a natural outcome from farm work and these machines are used for this as well. Attempts even were made to equip a standard tractor with change devices to accommodate a roller, converting it into a substitute for a steam roller, but this however was a flat failure.

The most successful tractor engine for threshing and belt work on the farm was not the best for these other classes of work, and for a plowing engine of smoother running qualities, a multiple cylinder gasoline tractor is designed. Because this same heavily constructed best threshing engine was too weighty for effective work on the draw bar for marshy or soft ground, track laying types of machines were designed and are being manufactured. This class of machine has made great progress in some parts of the country and there are now half a dozen manufacturers of such machines.

For the same reason the four-wheel-drive type was attempted and some of these were rather successfully developed, one in particular being even manufactured and placed on the market. Other forms of these have never gotten beyond the experimental tractor, while others have not advanced beyond the design stage. The advantage to be gained in the four-wheel-drive principle is greater traction and the equal distribution of power and weight to a greater number of points on the ground. It has been found that this type of tractor cannot be built to run efficiently, that is, with only slight power losses,

except at a prohibitive cost. This has prevented an efficient four-wheel-drive tractor from appearing on the market.

Some engineers have already conceived of the above and the trend has already started along the line of specialized machines, among which are to be found the track laying type, for conditions peculiar to some parts of the country.

Plowing machines, in which the only object is to plow and in which are found engine and plows mounted in the same frame as a unit, are now rapidly pushing to the front and in this way the work can be most efficiently accomplished. Threshing and other belt work has been and is being efficiently accomplished by self-propelled portable engines which represent a type of general purpose tractor machine.

These specialized machines which are now coming into use are gradually developing and the already partially created demand for the so-called farm tractor is being met by the manufacturer of the small machine which is capable of handling two of the above classes of work, namely, plowing and threshing. These machines have been rapidly pushed to the front by several manufacturers, and they are doing much toward limiting the requirements of a given machine to fewer classes of work, because they are called upon to do these two classes only. Gradually, although the time is not yet ripe, these two classes of work will be separated also.

A general canvass of the tractor situation by a person not a student of the business, would cause wonderment as to the great number of the differently designed machines, and as to why they are developed along such entirely different lines and yet are all termed tractors. The time is ripening, however, when we shall see as ultimate machines, a power threshing machine as a unit in itself, a plowing machine peculiar to that work only, a quick acting power rolling machine as a substitute for the steam roller, a power country road grading machine, a power traction machine for hauling wagon trains and other loads on highways, and a machine for belt work.

This condition has already asserted itself and the general use of the term tractor is becoming vague, for each tractor will have to be known and discussed with reference to its own field. This natural trend will give room for mechanical genius to put

forth its best efforts and develop machines most efficient in each class.

There will always be some conservative builders of machines in each class and there will be room for all in the eventual market. We are now in the midst of this rapid change or development of the so-called tractor business and many assertions are made by those who have not perceived the trend, that the day of the large tractor is passed. This is not the fact, for it is merely at a standstill, temporarily, until it again appears in its new form.

DISCUSSION

Mr. Rowley.

Mr. R. L. Rowley,* Junior Am. Soc. M. E., opened the discussion by stating the difficulty of standardizing the manufacture of automobile parts to be due to two causes; the changes made by the manufacturers themselves, as they find improvements and alterations necessary from actual operation of cars, and the variation in practice by the large number of manufacturers, each pursuing his own methods.

Mr. Meyer.

Mr. F. H. Meyer† said that the reason why manufacturers do not adhere to any one size or style is because trucks, for instance, are in a state of rapid development and improvement. Also, machines have to be constructed differently to suit different service and equipment. The trend is towards standards, but it is too early to carry this out, as we do not know what is necessary. The trend in trucks is towards the Hotchkiss worm drive and the practice of taking the torsion through the springs. The worm and wheel used to be considered an inefficient device, transmitting only about 60 percent of the power supplied to it. Today, by actual test, worm-and-wheel drives transmit 95% of the power supplied. A bronze wheel and steel worm are used to compensate for lengthening of the worm, due to expansion, and a special type of thrust bearing to take care of the thrust from the worm has improved the efficiency.

Automobile engineers should cooperate in giving each other the benefit of experience, and standardization could be more easily accomplished.

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* Board of Fire Underwriters, San Francisco, Calif.

† Auto Engr., San Francisco, Calif.